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Site Selection for the Monitoring of Photochemical Air Pollutants

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SITE SELECTION FOR THE MONITORING OF PHOTOCHEMICAL AIR POLLUTANTS

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Waste Management
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711

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SITE SELECTION FOR THE MONITORING OF PHOTOCHEMICAL AIR POLLUTANTS

by

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Prepared for

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Waste Management
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April 1978

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ABSTRACT

This report addresses the issues of (1) classifying monitoring objectives for the major pollutants involved in atmospheric photochemical reactions--the nonmethane hydrocarbons (NMHC), nitric oxide (NO), nitrogen dioxide (NO_2), and oxidants (O_x)--(2) devising a set of monitoring station types to meet those objectives; and finally (3) prescribing procedures for identifying suitable locations for the different types of monitoring stations. A literature review suggests that the objectives of past data gathering efforts can be classified according to the spatial area to be represented, the nature of the pollutant as a reactant or product photochemical processes, and sometimes, whether the impacts of a particular source are of concern. A site typology based on spatial representativity with subcategories dependent on more specialized monitoring objectives (i.e., source-oriented, product-oriented, or reactant-oriented objectives) is presented. The requirements for locating the different types of monitoring station have been outlined in flow chart form.

PREFACE

The intent of this report is to provide a comprehensive and up to date technical resource document to assist EPA, state and local air pollution control agencies, and other users in developing better and more effective monitoring networks for the photochemical pollutants. The information may be used by EPA in the future for developing more definitive guidelines and criteria for such monitoring. However, this report in itself does not constitute the official monitoring guideline of the Agency.

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1. SUMMARY

Pollution measurements are made for a wide variety of purposes, but attempts are seldom made to link physical characteristics of a sampling location with the problem being addressed. This may be because coherent schemes have not been devised for classifying sites and relating their characteristics to intended data use. A good site classification system is needed because monitoring stations operating for many years, at the cost of thousands of dollars for equipment, maintenance, and data processing, must be located where the data will satisfy the intended purposes. The costs of poor siting procedures go beyond the direct costs of establishing and operating the stations. Data used to plan large-scale air quality control programs must be sound if they are to warrant the economic and social impacts. Other data uses will have different requirements and different consequences, but in most cases there will be considerable justification for carefully matching monitoring sites with monitoring purposes.

The uses of air quality data can be broadly categorized as:

- Air quality assessment
- Development and evaluation of control plans
- Enforcement of regulations
- Research
- Public health studies
- Miscellaneous purposes.

Each category has its subcategories, but at no level of classification does this system directly relate to physical factors. A site classification system that can be used to define an appropriate set of physical characteristics for each site type must examine the uses of the data in terms of the physical factors that influence the data. For example, different monitoring purposes will have different levels of appropriate spatial smoothing. Sometimes it is necessary to provide data representative of a neighborhood within the city; other uses require the representation of larger areas. Spatial representativeness provides a basis for classifying stations and their uses. Furthermore, it has a physical basis that can help to define the required station characteristics.

The measurement scales that are of greatest importance for the photochemical pollutants are:

- Urban to regional scale, to define multi-neighborhood or citywide conditions on a scale from several kilometers up to larger suburban or rural areas of reasonably homogeneous geography and extending for several tens of kilometers.
- Neighborhood scale, to define concentrations within some extended area of the city that has relatively uniform land use; dimensions are of the order of a few kilometers.

Factors other than measurement scales have also been incorporated into the system for classifying the monitoring purposes. For the photochemical pollutants, there are differences related to the pollutants' roles as reactants and products. For example, the air quality guidelines for NMHC emphasize their role as reactants, while the oxidant standards are differently oriented. Even though the scales of interest might be similar for air quality monitoring of NMHC and O_x, the site selection processes will differ because of the intrinsic differences between reactants and products.

For any pollutant that has large individual sources, some monitoring is likely to be done to determine the impact of those sources on their surroundings. This source-oriented monitoring can have different siting requirements from other, more general monitoring objectives. The classification of objectives and the corresponding site types should take the differences into account.

This report describes a site classification system based on the considerations discussed above. Table 1 summarizes this system. The types of monitoring sites have been chosen to meet the major classes of monitoring data usage. Those classes were developed on the basis of

Table 1

SUMMARY OF IMPORTANT CHARACTERISTICS OF MONITORING SITE TYPES

<table>
<tr><th>General Site Type</th><th>Subtype</th><th>Scale to be Represented</th><th>Applicable Photochemical Pollutants</th><th>General Location Description</th><th>Specific Site and Inlet Requirements</th></tr>
<tr><td>Neighborhood</td><td>Source-Oriented</td><td>Small end of Neighborhood scale</td><td>NO,
NO_2
(NO_x)
and
NMHC</td><td>In area most likely to be heavily affected by emissions from the point source of interest. Can be determined from simple Gaussian models and climatological summaries.</td><td>Inlet 3 to 15 m high and away from vertical walls. Site should be separated from buildings, trees, etc. by about twice the height of the obstacle above the inlet. Separation from highways should be:
<table>
<tr><th>Average Daily Traffic (Vehicles)</th><th>Pollutant
NMHC</th><th>
NO/NO_2</th></tr>
<tr><td><1000</td><td>15 m</td><td>20 m</td></tr>
<tr><td>1,000-10,000</td><td>15-400 m</td><td>20-250 m</td></tr>
<tr><td>>10,000</td><td>>400 m</td><td>>250 m</td></tr>
</table></td></tr>
<tr><td>Neighborhood</td><td>General</td><td>Neighborhood, a few kilometers</td><td>NO,
NO_2
NMHC
and
O_x</td><td>In an area of homogenous land use, and sufficiently removed from individual sources and sinks to be representative. Areas subject to impact by large point sources should be avoided.</td><td>For defining typical population exposures, the site will be in a typical neighborhood in the central part of the urban area. Maximum concentrations will be found near maximum emissions for NO_x and NMHC; for O_x maxima see product catagories. Inlet should be 3 to 15 m high and away from vertical walls. Separation from highways should be:
<table>
<tr><th>Average Daily Traffic (Vehicles)</th><th>
O_x</th><th>Pollutant
NMHC</th><th>
NO/NO_2</th></tr>
<tr><td><1000</td><td>20 m</td><td>15 m</td><td>20 m</td></tr>
<tr><td>1,000-10,000</td><td>20-250 m</td><td>15-400 m</td><td>20-250 m</td></tr>
<tr><td>>10,000</td><td>>250 m</td><td>>400 m</td><td>250 m</td></tr>
</table></td></tr>
<tr><td>Neighborhood</td><td>Important Reactant Area</td><td>Large end of Neighborhood Scale</td><td>NO,
NO_2
NMHC</td><td>In areas where the emissions might be expected to serve as reactants to produce oxidants that would impact on sensitive regions. Candidate sites will be upwind of sensitive regions during photochemically active meteorological conditions, e.g. temperatures above 80^{o}F.</td><td>Inlet heights and separation from roadways should be the same as defined above. Areas subject to the impact of large individual sources should be identified (see discussion for source-oriented monitoring) and avoided.</td></tr>
<tr><td>Neighborhood</td><td>Important Product Area</td><td>Large end of Neighborhood Scale</td><td>O_x,
NO_2</td><td>In areas of important O_x and NO_2 concentrations Maximum O_x tends to be about 5 to 7 hours travel distance downwind (for photochemically active meteorological conditions) of the upwind edge of the city. If this distance falls within the urban area, the maxima will be found just outside the urbanized area. Maximum NO_2 concentrations tend to be displaced downwind of maximum NO_x emissions areas about one or two hours travel distance.</td><td>Inlet heights, roadway separations, distances from obstructions are the same as discussed above.</td></tr>
<tr><td>Urban/ Regional</td><td>General</td><td>Urban/ Regional Scale, tens of kilometers</td><td>NO,
NO_2
NMHC
and
O_x</td><td>Background sites should be upwind of the city, especially for photochemically active meteorological conditions. Distances vary from about 30 km for regions with a population of 200,000 to 140 km for the largest urban areas. If the site will be upwind under the most photochemically active conditions, the separations can be reduced. General monitoring for purposes other than defining background concentrations need not be so restrictive.</td><td>Inlet heights, roadway separations and distances from obstructions are similar to those given above.</td></tr>
</table>

spatial representativity, then subdivided according to the pollutant's role as a reactant or a product. The system also considers whether the impact of a major source is of concern.

Most common monitoring purposes can be matched to appropriate site types in Table 1, but this is only a part of a system of site types and site selection procedures. The application of the concept of spatial representivity to the selection of sampling sites generally depends on finding a location that will not be unduly influenced by specific sources or sinks--except for source-oriented monitoring. Sometimes, when human exposure is involved, relatively sensitive areas may be sought. These might be areas with high population density, or many aged or infirm people.

The site selection procedures and criteria for each of the pollutants have been summarized in a set of flow diagrams. Figure 1 shows the requirements for selecting a site for monitoring NMHC. The general locations are chosen to be representative of areas of major impact--either of an individual source, or an area where the reactants are most apt to lead to high levels of ozone impact. The specific recommendations for inlet locations that are shown have been chosen to minimize extraneous or very localized influences.

A summary of the steps for selecting monitoring sites for NO and NO_2 is shown in Figure 2. The minimum distance to roadways shown in the figure is based on an analysis that makes use of the quasi-steady state relationship among O_3, NO and NO_2 concentrations and Gaussian diffusion modeling. To some extent, the recommended setbacks represent a compromise between the ideal of minimal interference and the practicality of limited space. The locations of the general areas that are most suitable for monitoring are based on analysis of data from several areas--Los Angeles, San Francisco, St. Louis, Houston, the Northeast U.S., and southwest Ohio. Inlet locations were chosen to minimize extraneous influences.

Figure 3 summarizes the procedures for selection of oxidant monitoring sites. The general locations are based on the scale of representativeness desired, i.e. neighborhood or regional. As with NO_x, suggested guidance for locating the general areas that are suitable is based on analysis of ozone data from five specific urban or interurban areas.

In summary, the guidance presented here will serve as a technical basis for selecting sites that can be classified into a limited number of types. The standardization of physical characteristics will ensure that comparison among sites of the same type will not be clouded by peculiarities in the siting. Use of the classification scheme does more than ensure compatibility of data and allow reasonable comparisons among stations of the same type. It also provides a physical basis for the interpretation and application of those data. This should help to prevent mismatches between what the data actually represent and what they are interpreted to represent.

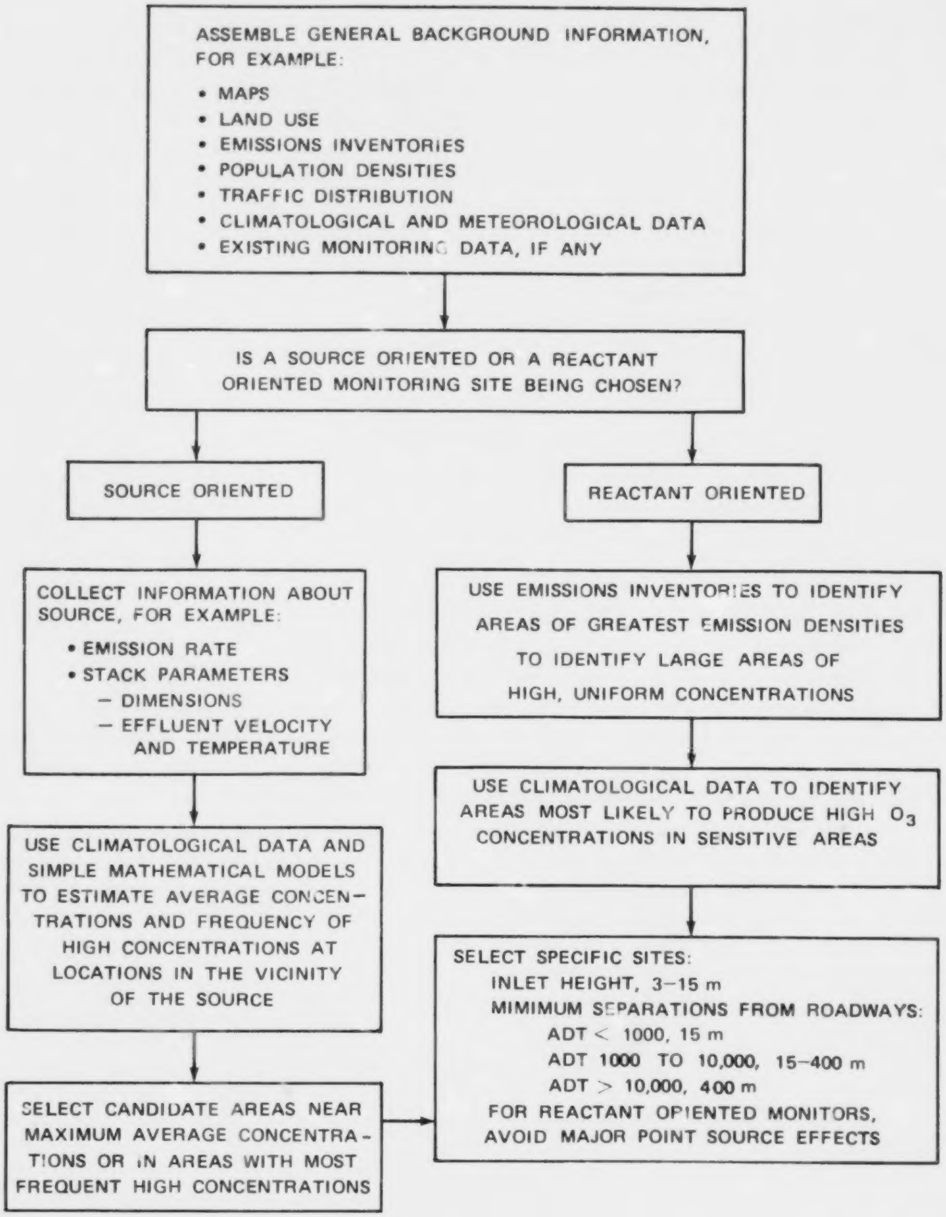
ASSEMBLE GENERAL BACKGROUND INFORMATION, FOR EXAMPLE:
• MAPS
• LAND USE
• EMISSIONS INVENTORIES
• POPULATION DENSITIES
• TRAFFIC DISTRIBUTION
• CLIMATOLOGICAL AND METEOROLOGICAL DATA
• EXISTING MONITORING DATA, IF ANY
IS A SOURCE ORIENTED OR A REACTANT ORIENTED MONITORING SITE BEING CHOSEN?
SOURCE ORIENTED
REACTANT ORIENTED
COLLECT INFORMATION ABOUT SOURCE, FOR EXAMPLE:
• EMISSION RATE
• STACK PARAMETERS
– DIMENSIONS
– EFFLUENT VELOCITY AND TEMPERATURE
USE CLIMATOLOGICAL DATA AND SIMPLE MATHEMATICAL MODELS TO ESTIMATE AVERAGE CONCENTRATIONS AND FREQUENCY OF HIGH CONCENTRATIONS AT LOCATIONS IN THE VICINITY OF THE SOURCE
SELECT CANDIDATE AREAS NEAR MAXIMUM AVERAGE CONCENTRATIONS OR IN AREAS WITH MOST FREQUENT HIGH CONCENTRATIONS
USE EMISSIONS INVENTORIES TO IDENTIFY AREAS OF GREATEST EMISSION DENSITIES TO IDENTIFY LARGE AREAS OF HIGH, UNIFORM CONCENTRATIONS
USE CLIMATOLOGICAL DATA TO IDENTIFY AREAS MOST LIKELY TO PRODUCE HIGH O3 CONCENTRATIONS IN SENSITIVE AREAS
SELECT SPECIFIC SITES:
INLET HEIGHT, 3–15 m
MIMIMUM SEPARATIONS FROM ROADWAYS:
ADT < 1000, 15 m
ADT 1000 TO 10,000, 15–400 m
ADT > 10,000, 400 m
FOR REACTANT ORIENTED MONITORS, AVOID MAJOR POINT SOURCE EFFECTS

FIGURE 1 SCHEMATIC DIAGRAM OF PROCEDURE FOR SELECTING NMHC MONITORING SITES

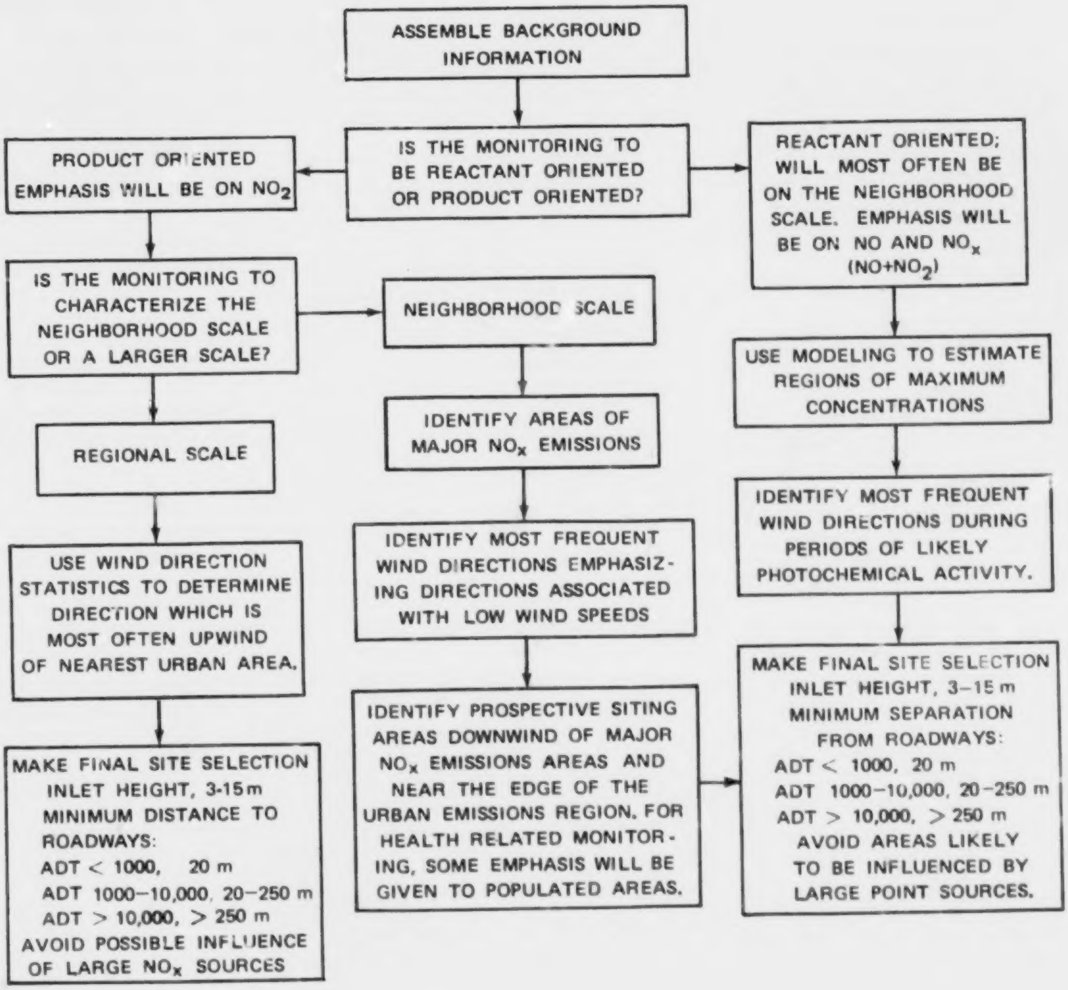
ASSEMBLE BACKGROUND INFORMATION
IS THE MONITORING TO BE REACTANT ORIENTED OR PRODUCT ORIENTED?
PRODUCT ORIENTED EMPHASIS WILL BE ON NO_2
REACTANT ORIENTED; WILL MOST OFTEN BE ON THE NEIGHBORHOOD SCALE. EMPHASIS WILL BE ON NO AND NO_x ($NO+NO_2$)
IS THE MONITORING TO CHARACTERIZE THE NEIGHBORHOOD SCALE OR A LARGER SCALE?
NEIGHBORHOOD SCALE
USE MODELING TO ESTIMATE REGIONS OF MAXIMUM CONCENTRATIONS
REGIONAL SCALE
IDENTIFY AREAS OF MAJOR NO_x EMISSIONS
IDENTIFY MOST FREQUENT WIND DIRECTIONS DURING PERIODS OF LIKELY PHOTOCHEMICAL ACTIVITY.
USE WIND DIRECTION STATISTICS TO DETERMINE DIRECTION WHICH IS MOST OFTEN UPWIND OF NEAREST URBAN AREA.
IDENTIFY MOST FREQUENT WIND DIRECTIONS EMPHASIZING DIRECTIONS ASSOCIATED WITH LOW WIND SPEEDS
MAKE FINAL SITE SELECTION INLET HEIGHT, 3–15 m MINIMUM SEPARATION FROM ROADWAYS: ADT < 1000, 20 m ADT 1000–10,000, 20–250 m ADT > 10,000, > 250 m AVOID AREAS LIKELY TO BE INFLUENCED BY LARGE POINT SOURCES.
IDENTIFY PROSPECTIVE SITING AREAS DOWNWIND OF MAJOR NO_x EMISSIONS AREAS AND NEAR THE EDGE OF THE URBAN EMISSIONS REGION. FOR HEALTH RELATED MONITORING, SOME EMPHASIS WILL BE GIVEN TO POPULATED AREAS.
MAKE FINAL SITE SELECTION INLET HEIGHT, 3-15m MINIMUM DISTANCE TO ROADWAYS: ADT < 1000, 20 m ADT 1000–10,000, 20–250 m ADT > 10,000, > 250 m AVOID POSSIBLE INFLUENCE OF LARGE NO_x SOURCES

FIGURE 2 SCHEMATIC DIAGRAM OF PROCEDURE FOR SELECTING NEIGHBORHOOD AND REGIONAL SCALE MONITORING SITES FOR NO AND NO_2

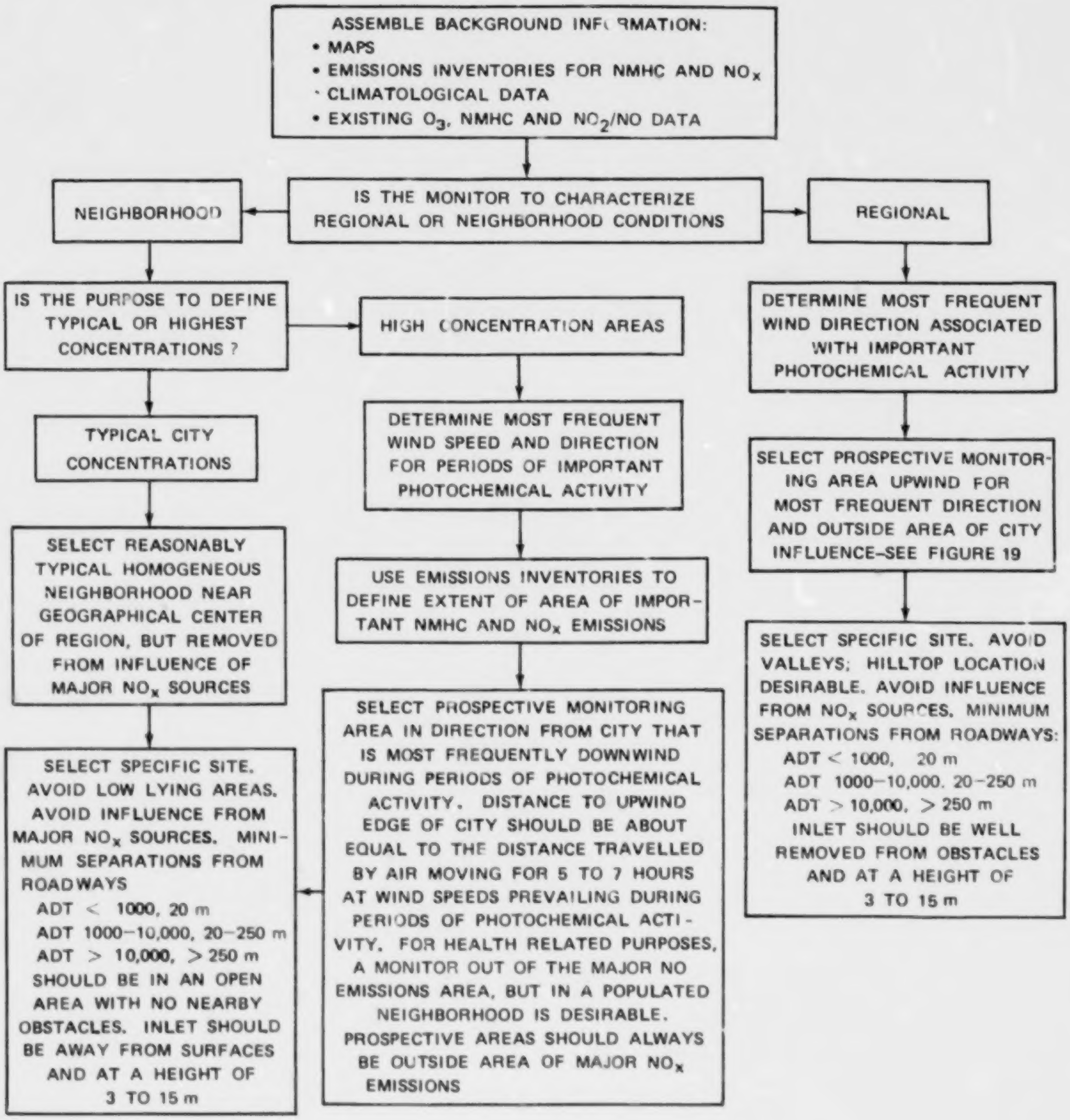
ASSEMBLE BACKGROUND INFORMATION:
• MAPS
• EMISSIONS INVENTORIES FOR NMHC AND NO$_x$
• CLIMATOLOGICAL DATA
• EXISTING O$_3$, NMHC AND NO$_2$/NO DATA
IS THE MONITOR TO CHARACTERIZE REGIONAL OR NEIGHBORHOOD CONDITIONS
NEIGHBORHOOD
REGIONAL
IS THE PURPOSE TO DEFINE TYPICAL OR HIGHEST CONCENTRATIONS ?
HIGH CONCENTRATION AREAS
DETERMINE MOST FREQUENT WIND DIRECTION ASSOCIATED WITH IMPORTANT PHOTOCHEMICAL ACTIVITY
TYPICAL CITY CONCENTRATIONS
DETERMINE MOST FREQUENT WIND SPEED AND DIRECTION FOR PERIODS OF IMPORTANT PHOTOCHEMICAL ACTIVITY
SELECT PROSPECTIVE MONITORING AREA UPWIND FOR MOST FREQUENT DIRECTION AND OUTSIDE AREA OF CITY INFLUENCE–SEE FIGURE 19
SELECT REASONABLY TYPICAL HOMOGENEOUS NEIGHBORHOOD NEAR GEOGRAPHICAL CENTER OF REGION, BUT REMOVED FROM INFLUENCE OF MAJOR NO$_x$ SOURCES
USE EMISSIONS INVENTORIES TO DEFINE EXTENT OF AREA OF IMPORTANT NMHC AND NO$_x$ EMISSIONS
SELECT SPECIFIC SITE. AVOID VALLEYS; HILLTOP LOCATION DESIRABLE. AVOID INFLUENCE FROM NO$_x$ SOURCES. MINIMUM SEPARATIONS FROM ROADWAYS:
ADT < 1000, 20 m
ADT 1000–10,000, 20–250 m
ADT > 10,000, > 250 m
INLET SHOULD BE WELL REMOVED FROM OBSTACLES AND AT A HEIGHT OF 3 TO 15 m
SELECT SPECIFIC SITE. AVOID LOW LYING AREAS. AVOID INFLUENCE FROM MAJOR NO$_x$ SOURCES. MINIMUM SEPARATIONS FROM ROADWAYS
ADT < 1000, 20 m
ADT 1000–10,000, 20–250 m
ADT > 10,000, > 250 m
SHOULD BE IN AN OPEN AREA WITH NO NEARBY OBSTACLES. INLET SHOULD BE AWAY FROM SURFACES AND AT A HEIGHT OF 3 TO 15 m
SELECT PROSPECTIVE MONITORING AREA IN DIRECTION FROM CITY THAT IS MOST FREQUENTLY DOWNWIND DURING PERIODS OF PHOTOCHEMICAL ACTIVITY. DISTANCE TO UPWIND EDGE OF CITY SHOULD BE ABOUT EQUAL TO THE DISTANCE TRAVELLED BY AIR MOVING FOR 5 TO 7 HOURS AT WIND SPEEDS PREVAILING DURING PERIODS OF PHOTOCHEMICAL ACTIVITY. FOR HEALTH RELATED PURPOSES, A MONITOR OUT OF THE MAJOR NO EMISSIONS AREA, BUT IN A POPULATED NEIGHBORHOOD IS DESIRABLE. PROSPECTIVE AREAS SHOULD ALWAYS BE OUTSIDE AREA OF MAJOR NO$_x$ EMISSIONS

FIGURE 3 SCHEMATIC DIAGRAM OF PROCEDURE FOR SELECTING OXIDANT MONITORING SITES

2. INTRODUCTION

2.1. Purpose

As awareness of air pollution and its effects increases, so does the importance of measuring the concentrations of the various air pollutants. Unrepresentative data may be misleading and of less value than no data at all, even though the cost of poor data will not differ much from the cost of high quality data. It is not surprising that a proper methodology for the collection of air quality data should be of concern. This report focuses on the identification of suitable locations for monitoring pollutants related to photochemical oxidant formation, i.e.:

- Nonmethane hydrocarbons (NMHC)
- Nitrogen dioxide (NO_2)
- Nitric oxide (NO)
- Oxidants (O_x)

2.2. General Approach

The establishment of siting criteria for monitoring stations starts by finding why the pollutants of interest are monitored. Siting criteria describe the proper physical location of a monitor, so they are physically related to the reasons for monitoring. The second step toward finding siting criteria for different monitoring purposes is to categorize the purposes according to a physically based classification system. The final step is to review existing data and interpret those data in such a way that specific siting criteria can be recommended.

This report reviews the reasons for monitoring pollutants, and then a physically based system for classifying these reasons is described. The discussions of the siting criteria and their derivation have been prefaced with a section that discusses pollutants of interest, their sources, physical characteristics. Most of the data and analyses that led to the final siting recommendations are discussed in the last section of the report.

3. IMPORTANT CHARACTERISTICS OF THE PHOTOCHEMICAL POLLUTANTS

3.1. Nonmethane Hydrocarbons

3.1.1. General

The analysis of urban air for individual, nonmethane hydrocarbons (NMHC) has revealed the presence of so many different compounds that it is very difficult to specify a set of characteristics defining "hydrocarbons." However, the reference method for the determination of hydrocarbons defines the hydrocarbons of interest to be those compounds that pass through a filter with a porosity of 3 to 5μm and that cause a flame ionization detector to give a signal (Lawrence Berkeley Laboratory--LBL, 1973). In addition to the many compounds involved, another complication encountered when measuring hydrocarbons is the large amount of natural methane present compared with the other hydrocarbon molecules. The methane concentration is usually more than the concentration of the rest of the hydrocarbons combined, but methane is not considered an important pollutant (Public Health Service--PHS, 1970a) because it does not react appreciably to form harmful compounds. For most purposes, the hydrocarbons other than methane are of interest, hence, the desire to measure "nonmethane hydrocarbons." The most important characteristic of the NMHC, from an air pollution standpoint, is their ability to enter into reactions with other compounds to produce secondary, harmful contaminants.

3.1.2. Sources of NMHC

Table 2 shows the nationwide estimates of hydrocarbon emissions for 1975. The table shows highway vehicles to be very important sources of hydrocarbons. Organic solvent usage and refining are other major sources of hydrocarbon emissions. These source types illustrate the two major categories; mobile and stationary. Mobile sources are mainly comprised of gasoline powered vehicles with a small contribution from other types of vehicles, including aircraft and diesel engines.

3.1.3. Reactions

A complete description of the complex reactions by which oxidants arise from the NMHC is beyond the scope of this report, but a simplified summary can be given. The starting point is nitrogen dioxide (NO_2), a product formed by the oxidation of nitric oxide (NO) which is formed during combustion. In the absence of hydrocarbons, NO_2 is dissociated by sunlight to produce NO and an oxygen atom. The oxygen atom combines with the atmospheric molecular oxygen to produce ozone (O_3) which then combines with the NO to produce NO_2. Then, as shown schematically in Figure 4, the process begins anew. Actually, the process is continuous and there are equilibrium concentrations for each of the species. Photochemical oxidant concentrations are increased when the steady state of the NO_2 photolytic cycle is disrupted by NMHC that react with the NO to unbalance the cycle. Then ozone builds up to redress the balance. Figure 5 schematically illustrates the role of hydrocarbons. Hydrocarbons also react with atomic oxygen to produce oxidized compounds and free radicals which react with NO to further change the photolytic equilibrium.

3.2. Nitric Oxide and Nitrogen Dioxide

3.2.1. General

Nitric Oxide (NO) is formed during the combustion of fossil fuels. Currently, there is no evidence that NO is a health hazard at concentrations normally found in the atmosphere (EPA, 1971). Concern over the ambient levels of this gas and their relation to air quality arises because NO is frequently oxidized to form nitrogen dioxide (NO_2). Nitrogen dioxide is not only toxic, it is also corrosive and highly oxidizing. Small amounts of NO_2, usually less than 0.5 percent, are formed directly during high temperature combustion. Some NO_2, less than 10 percent, is formed by the direct oxidation of NO in the short interval between the ejection of

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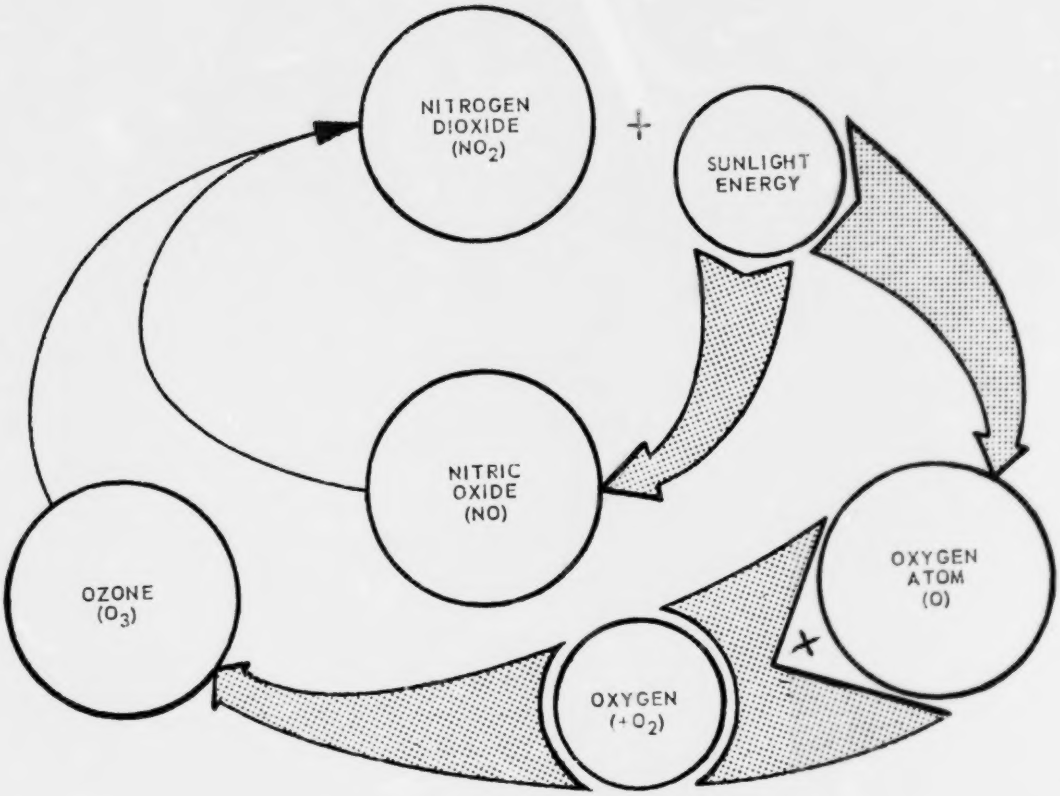
Table 2

NATIONWIDE ESTIMATES OF HYDROCARBON EMISSIONS, 1975

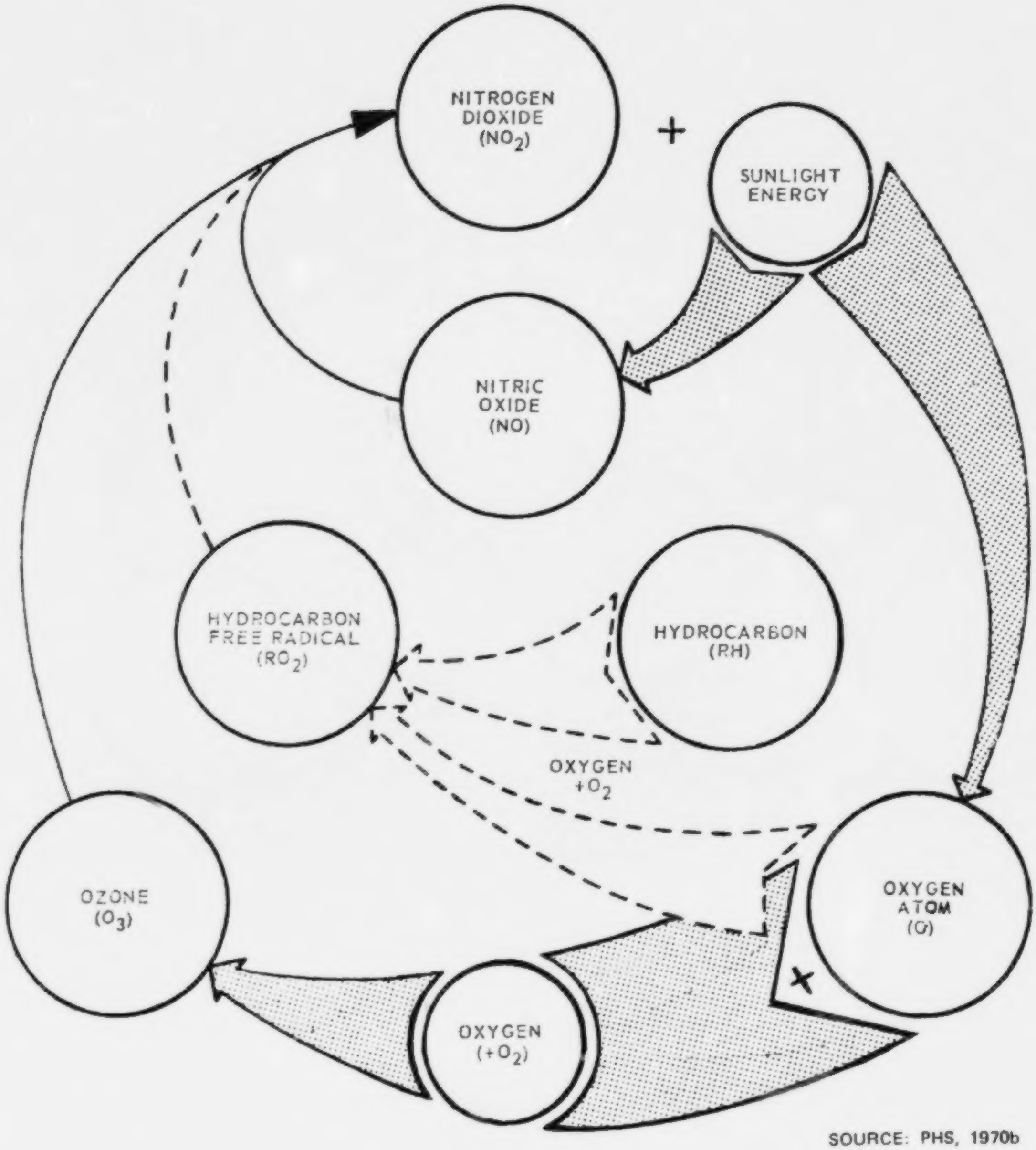
Source Category	Emissions 10^6 tons/year	Percent of Total
Transportation	11.7	37.9
Highway	10.0	32.4
Non-Highway	1.7	5.5
Stationary Fuel Combustion	1.4	4.5
Electric Utilities	0.1	0.3
Other	1.3	4.2
Industrial Processes	3.5	11.3
Chemicals	1.6	5.2
Petroleum Refining	0.9	2.9
Metals	0.2	0.6
Other	0.8	2.6
Solid Waste	0.9	2.9
Miscellaneous	13.4	43.4
Forest Wildfires	0.6	1.9
Forest Managed Burning	0.2	0.6
Argricultural Burning	0.1	0.2
Coal Refuse Burning	0.1	0.2
Structural Fires	<0.1	0.1
Organic Solvents	8.3	26.8
Oil and Gas Production and Marketing	4.2	13.6
Total	30.9	100.0

Source: Hunt, et al, 1976


NITROGEN DIOXIDE (NO_2)
+
SUNLIGHT ENERGY
NITRIC OXIDE (NO)
OXYGEN ATOM (O)
+
OZONE (O_3)
OXYGEN $(+O_2)$

SOURCE: PHS, 1970b

FIGURE 4. ATMOSPHERIC NITROGEN DIOXIDE PHOTOLYTIC CYCLE


NITROGEN DIOXIDE (NO_2)
+
SUNLIGHT ENERGY
NITRIC OXIDE (NO)
HYDROCARBON FREE RADICAL (RO_2)
HYDROCARBON (RH)
OXYGEN $+O_2$
OZONE (O_3)
OXYGEN ATOM (O)
OXYGEN ($+O_2$)
X

SOURCE: PHS, 1970b

FIGURE 5. INTERACTION OF HYDROCARBONS WITH THE ATMOSPHERIC NITROGEN DIOXIDE PHOTOLYTIC CYCLE

NO as an exhaust product and the time when it is diluted to concentrations below 1 ppm. Most of the NO_2 found in the atmosphere results from the oxidation of NO to NO_2 in the presence of sunlight, ozone and hydrocarbons. The other oxides of nitrogen in the atmosphere have not been considered because they are present only at very low concentrations or they are photochemically nonreactive.

3.2.2. Sources

Table 3 shows the nationwide, anthropogenic emissions for NO_x. Stationary fuel combustion accounted for over half of the total in 1975. Transportation is the other major source, accounting for over 44 percent of the total amount emitted. Other minor contributors were solid waste disposal and industrial processes.

3.2.3. Reactions

The participation of oxides of nitrogen in the photochemical process was illustrated schematically in Figures 4 and 5. The example of diurnal changes of O_3, NO and NO_2 concentration shown in Figure 6 also illustrates some of the photochemical phenomena. Before daylight, on this particular day in Los Angeles, the concentrations of NO and NO_2 remain relatively constant. As urban activity increases from 6 to 8 a.m., the concentrations of the primary pollutants, CO and NO, increase dramatically. Then, in response to increasing solar ultraviolet radiation, the amount of NO_2 increases as NO is converted to NO_2. As the NO concentration falls to very low levels (less than 0.1 ppm), photochemical oxidants begin to accumulate and reach a peak about midday. The increase in automobile traffic in late afternoon and evening caused an increase in the NO concentration. Even in the absence of sunlight, NO_2 continues to be formed from NO by ozone until the O_3 supply is exhausted.

3.3. Photochemical Oxidants

Oxidants are defined as those atmospheric substances that will oxidize specified reagents; potassium iodide is the most common of these reagents. The most abundant of these oxidants is O_3. For this reason, the term oxidant and ozone are often used interchangeably. In general, we do not distinguish between the two in this report. Ozone is not usually emitted directly into the atmosphere, but is instead a secondary pollutant that is formed over a period of time from a variety of atmospheric reactants. Ozone interacts with the environment more than any other ambient pollutant. It reacts with other pollutants, with vegetation, with sampling probes, and it is easily destroyed by these reactions. Ozone's reaction with NO causes the amount of ozone near highways to be much lower than that found nearby, away from the road.

As Figure 6 shows, the oxidant concentration is apt to reach a peak later than the concentrations of the hydrocarbons and oxides of nitrogen from which it is formed. Oxidant formation is affected by the intensity and duration of sunlight, temperature, and the emissions and dilution processes affecting atmospheric concentrations of the other particpants in the photochemical reactions. The relationship between the primary emissions of NO_x and NMHC and the subsequent formation of atmospheric ozone is difficult to quantify. The slow formation and the transport of secondary pollutants tend to produce large separations, spatially and temporally between the major sources and the areas of high oxidant pollution.

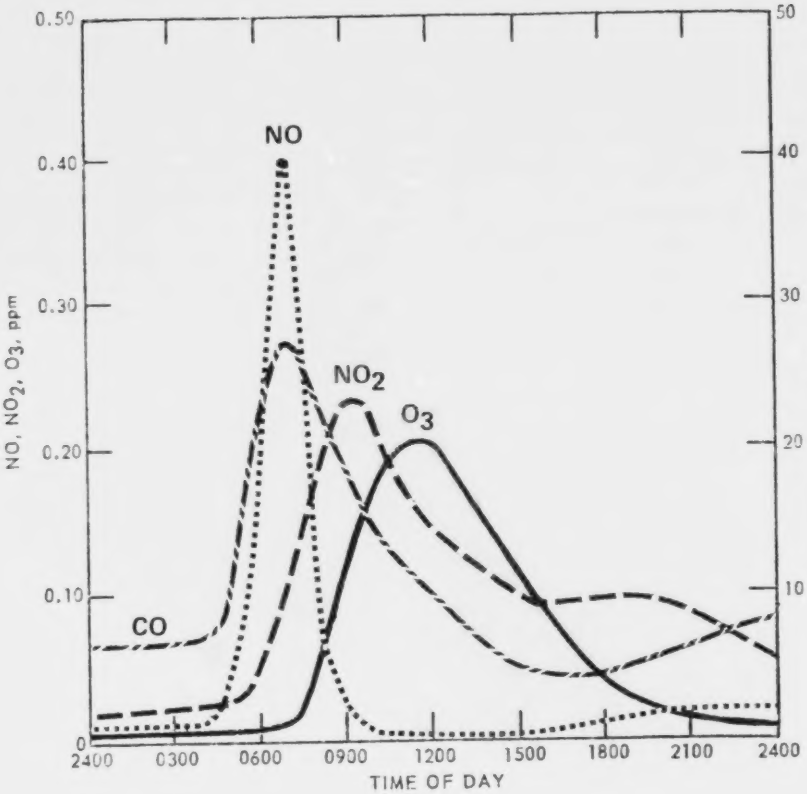
There are a few primary sources of ozone, usually involving electrical discharge. In general, these are not important contributors to observed urban concentrations, except in their immediate vicinity. Ozone can also be brought to the surface from the stratosphere where it is formed by photodissociation of oxygen and recombination to ozone. Ozone accumulations have been observed frequently within inversion layers over urban and rural areas (Johnson and Singh, 1975; Miller and Ahrens, 1970; Pitts, 1973). Convection can bring these elevated layers to the surface.

Table 3

NATIONWIDE ESTIMATES OF OXIDES OF NITROGEN EMISSIONS, 1975

Source Category	Emissions 10^6 tons/year	Percent of Total
Transportation	10.7	44.2
Highway	8.2	33.9
Non-Highway	2.5	10.3
Stationary Fuel Combustion	12.4	51.2
Electric Utilities	6.8	28.1
Other	5.6	23.1
Industrial Processes	0.7	2.9
Chemicals	0.3	1.2
Petroleum Refining	0.3	1.2
Mineral Products	0.1	0.4
Other	<0.1	<0.1
Solid Waste	0.2	0.8
Miscellaneous	0.2	0.9
Forest Wildfires	0.1	0.4
Forest Managed Burning	<0.1	<0.1
Agricultural Burning	<0.1	<0.1
Coal Refuse Burning	0.1	0.4
Structural Fires	<0.1	<0.1
Total	24.2	100.0

Source· Hunt, et al., 1976



SOURCE: EPA, 1971

FIGURE 6. AN EXAMPLE OF DIURNAL CHANGES IN THE CONCENTRATIONS OF SELECTED POLLUTANTS IN LOS ANGELES

3.4. National Air Quality Standards

The air quality standards for the photochemical pollutants are summarized in Table 4. The underlying motivation for all the primary standards is the protection of public health. Ambient air standards for oxidants were chosen to keep the hourly level at less than 0.08 ppm (Schuck et al., 1970) to provide a margin of safety.

Although NMHC at the usual ambient levels are not generally considered to constitute a health hazard, some studies have shown that an average 6-9 a.m. concentration of 0.24 ppm of NMHC can produce a maximum hourly average concentration of ozone of up to 0.1 ppm (Schuck et al., 1970; Dimitriades, 1972). To keep oxidant levels below this value, guidelines for NMHC were chosen to be a maximum of 0.24 ppm for the 6-9 a.m. average concentration, not to be exceeded more than once each year. However, these guidelines are only applicable in areas where the other precursors necessary to produce violations of the oxidant standard are also present.

Recently, the joint effects on ozone production of the hydrocarbons and the oxides of nitrogen have been considered in the formulation of urban ozone control strategies. Figure 7 is a representation of the relationship among the initial concentrations of NO_x and NMHC and the amounts of O_3 that can be produced in the presence of sufficient sunlight. It is apparent from Figure 7 that the NMHC guidelines could be exceeded in rural areas with very low NO_x concentrations without resulting in oxidant violations. Thus, there is an implied caveat to the measurement of NMHC for purposes of assessing whether oxidant standards are likely to be violated, i.e., the presence of sufficient NO_x for photochemical production of ozone is assumed. The primary and secondary standards for NO_2 are 0.05 ppm, based on an annual arithmetic average.

TABLE 4

NATIONAL AIR QUALITY STANDARDS FOR THE PHOTOCHEMICAL POLLUTANTS

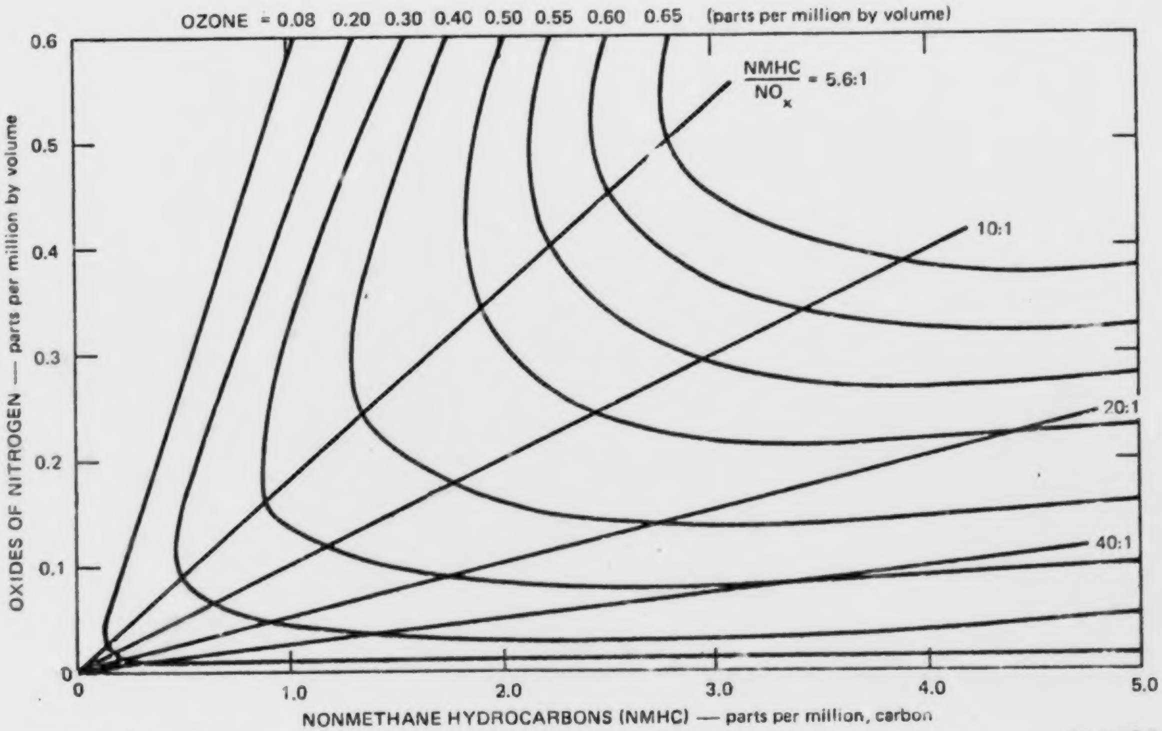
(Source: Fed. Reg., 1971)

Pollutant	Averaging Time	Primary Standards[b]	Secondary Standards[c]	Federal Reference Principle
Photochemical Oxidants (corrected for NO_2 and SO_2)	1 hour	160 µg/m (0.08 ppm)	Same as primary standard	Gas phase chemiluminescence
Hydrocarbons (corrected for methane)	3 hours 9-6 a.m.	160 µg/m^3 (0.24 ppm)	Same as primary standard	Gas chromatography -- flame ionization detection.
Nitrogen Dioxide	Annual Arithmetic Mean[a]	100 µg/m^3 (0.05 ppm)	Same as primary standard	Gas phase chemiluminescence

[a] National standards other than those based on annual arithmetic means or annual geometric means are not to be exceeded more than once per year.

[b] National Primary Standards: The levels of air quality necessary, with an adequate margin of safety, to protect the public health. The hydrocarbon standard is used only as a guide in devising implementation plans to achieve oxidant standards.

[c] National Secondary Standards: The levels of air quality necessary to protect the public welfare from any known or anticipated adverse effects to a pollutant.



SOURCE: Dodge, M.C., 1977.

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FIGURE 7 RELATIONSHIP AMONG NO_x AND NMHC CONCENTRATIONS AND POTENTIAL OZONE FORMATION

4. MONITORING OBJECTIVES AND SITE TYPES

4.1. General

Table 5 summarizes some of the common monitoring objectives. Each pollutant to which a particular objective applies is marked by an "X" in an appropriate column. The monitoring purposes listed in Table 5 are grouped into five general categories and one miscellaneous group. The table shows that not all purposes apply to all pollutants. For example, toxic pollutants may be monitored for purposes related to their effect on humans, while the nontoxic materials may be monitored for other reasons. This section discusses factors that are important to the siting of monitors for photochemical pollutants and to the development of a site classification system.

4.2. Important Principles for the Classification of Monitoring Objectives

Any site classification scheme should have a physical basis. A useful classifiction system can be devised on the basis of the spatial area that is to be represented by the measurements. This is a good example of a physical rationale for classification of monitoring purposes. The secondary pollutants, particularly oxidant, require appreciable formation time. Hence, mixing of reactants and products through large volumes of air will occur. This mixing reduces the importance of monitoring small-scale spatial variability. The monitoring of small-scale variability of the primary pollutants may sometimes be of only marginal importance also. For instance, the reasons for monitoring NMHC are usually related to the role of hydrocarbons in the production of oxidant. This role is accomplished only after a considerable elapsed time and large scale mixing. Again, mixing tends to produce uniformity in the distribution of the products. That uniformity in turn reduces the importance of measuring the small scale variability in the distribution of the primary reactants.

There are several kinds of sources of primary pollutants. For some monitoring objectives, the nature of the source will influence the desired characteristics of the monitoring site. Some emissions are the product of numerous small individual sources. Other emissions may be produced in large quantities from a small number of localized sources. Furthermore, the localized sources may be at ground level, or they may be elevated. Combinations of these source types are quite common.

Finally, meteorological factors are important to the site selection process. For example, when monitoring secondary pollutants, one must identify areas generally downwind of the primary pollutant sources during periods of strong oxidant formation. It will be important to consider the winds, in combination with the length of time required for the oxidant to form, and the locations of the major sources of the reactants. Meteorological factors also affect the selection of monitoring sites for primary pollutants, particularly when it is important to monitor the impact of a single, large, elevated source. In such cases, the areas of maximum impact will be governed by climatological factors. The frequency of occurrence of certain combinations of wind speed, wind direction, and atmospheric stability will govern when and where the plume from an elevated source of primary pollutants has its greatest ground level impact. Meteorological factors are also important for the location of areas where secondary pollutants reach their highest concentrations.

A site classification system should distinguish between source-oriented monitoring and monitoring which is not directed toward the determination of the effects from large, individual sources. Some distinction is necessary between the primary and the secondary pollutants; that is, between reactants and products.

In summary, the following physical factors need to be considered in classifying monitoring objectives and assigning site types:

1. Whether the effects of a single, large source are to be typified or excluded.
2. Atmospheric chemical reactions and whether the monitoring is supposed to provide information about the reactants or the products.

Table 5

MONITORING OBJECTIVES FOR NHMC, NO, NO$_2$, AND O$_x$

PURPOSE	POLLUTANT			
	NHMC	NO	NO$_2$	O$_x$
AIR QUALITY ASSESSMENT				
• Determine current air quality and trends	X	X	X	X
ENFORCEMENT OF REGULATIONS				
• Determine compliance with Air Quality Standards				
- Federal primary	X		X	X
- State or local	X		X	X
• Provide data for preparation of environmental impact statements	X		X	X
DEVELOPMENT AND EVALUATION OF CONTROL PLAN				
• Evaluate results of control measures				
- Local	X	X		
- Larger area			X	X
RESEARCH - ORIENTATION				
• Evaluate the contribution to observed concentration of specific sources, by type and location of emissions				
- Natural	X			X
- Man-made	X	X	X	
• Provide information on chemical reactions involving the pollutants and their reactivity	X	X	X	X
• Provide a basis for describing processes that affect pollutant concentration	X	X	X	X
• Test monitoring equipment	X	X	X	X
PUBLIC HEALTH				
• Determine long-term trends	X	X	X	X
• Provide a basis for invoking short-term or emergency control measures	X	X	X	X
MISCELLANEOUS				
• Evaluate effects of exposure on humans			X	X
• Determine effects on plants, animals, and materials			X	X
• Assess representatives of existing monitoring sites	X	X	X	X

3. The scale to be represented, especially:
   - Neighborhood, and
   - Urban to Regional.

The spatial scales of interest can be defined as follows.

Neighborhood: Measurements in this category would represent conditions throughout some reasonably homogeneous urban subregion, with dimensions of a few kilometers. Homogeneity refers to pollutant concentrations. These kinds of stations would provide information relating to health effects and compliance with regulations because they will also represent conditions in areas where people live and work. Neighborhood-scale data will provide valuable information for developing, testing, and revising concepts and models that describe the urban/regional concentration patterns. They will be useful to the understanding and definition of processes that take hours to occur and hence involve considerable mixing and transport.

Urban to Regional: This scale of measurement would be used to typify concentrations over very large portions of a metropolitan area and even larger rural areas with dimensions of as much as hundreds of kilometers. Such measurements would be useful for assessing trends in city-wide air quality and the effectiveness of larger scale air pollution control strategies. Measurements that represent a city-wide area will also serve as a valid basis for comparisons among different cities.

4.3. Site Types to Meet the Monitoring Objectives

When the monitoring objectives have been classified, site types can be identified that will meet the important objectives. Most monitoring objectives for the photochemical pollutants stress neighborhood and larger scales of representativeness. The importance of source-oriented monitors, or reactant-versus-product oriented monitors, is different for each of the pollutants.

4.3.1. Site Types for Monitoring NMHC

The most important monitoring objectives for NMHC require specification of concentrations on the urban-to-regional scale with due consideration given to the role of the NMHC in the formation of oxidants. Other objectives require neighborhood scale measurements to identify contributions of specific sources. The important site types for NMHC would be "urban/regional" and "neighborhood". Each of these has two subtypes. For the "neighborhood" site, the subtypes are "general" and "source characterization." For the "urban/regional" sites, important subtypes are "general" and "important reactant area".

4.3.2. Site Types for Monitoring NO

The most important monitoring objectives for NO are the same as for NMHC, because both are important to the formation of photochemical pollution, but are generally not considered toxic at ambient levels. The site types required to meet the most important objectives of NO monitoring will be the same as those for NMHC. This does not necessarily mean that the individual sites would be collocated. For example, an "urban/regional site--important reactant area" might be in a different place for NO than for NMHC because of differences in source distributions.

4.3.3. Site Types for Monitoring NO_2

Objectives that require neighborhood scale measurements are common in monitoring NO_2 because of the pollutant's toxicity. There are four possible subtypes:

- General
- Source characterization
- Important reactant area
- Important product area

Urban/regional site types are also considered important for NO_2 monitoring.

4.3.4. Site Types for Monitoring Ox

Many of the most important oxidant monitoring objectives are related to its status as a product in the photochemical process and most require measurements that represent the larger scale features of O_x distribution. Therefore, the appropriate sites should be located so that the product nature of the pollutant is emphasized.

4.4. Summary of Monitoring Site Taxonomy for the Photochemical Pollutants

Table 6 summarizes a suggested set of site types that should meet nearly all the important monitoring objectives. In subsequent sections, the requirements for locating sites of the suggested types will be explored. The site classifications shown in Table 6 were derived to meet the important requirements of photochemical pollutant monitoring. The classification scheme is related to similar approaches that have been applied before to the problem of deriving site types for carbon monoxide monitoring (e.g., Ott, 1975; Ludwig and Kealoha, 1975), sulfur dioxide monitoring (Ball and Anderson, 1977), and for particulate sampling (Ludwig, Kealoha, and Shelar, 1977). This provides a common basis for site selection that leads to similar monitoring site types for the different pollutants so that integrated, multipurpose monitoring will often be feasible.

Table 6

MONITORING SITE TYPES FOR THE PHOTOCHEMICAL POLLUTANTS

General Site Type	Subclass	Scale to be Represented	Other Important Factors	Photochemical Pollutants to which most applicable	Remarks
Neighborhood	Source-oriented	Smaller end of the neighborhood scale, 1-2 km	Areas where measurements will identify contributions of specific sources	NO_2, NMHC, NO	
Neighborhood	General	Neighborhood	Areas where measurements will be dominated by single sources are to be avoided	NO_2, NMHC, O_x NO	Similar to source oriented site, but not as restrictive
Urban/regional	Important reactant area	Urban/Regional tens of km.	Areas where reactants are expected to contribute importantly to photochemical air quality especially in sensitive receptor areas	NO, NMHC, NO_2	
Urban/regional	Important product area	Urban/Regional	Areas where important photochemical pollutant products are expected to occur	O_x, NO_2	**Composite of neighborhood observations**
Urban/regional	General	Urban/Regional	Areas where measurements are representative of whole region without regard to its importance in larger scale photochemical processes	NO, NO_2, NMHC, O_x	Similar to other urban/regional sites, but not so restrictive
Traffic effects	Street canyon or traffic corridor	Middle, on the scale of streets	Must be a large traffic source of NO nearby	NO, NO_2, O_x	Specifically to assess the impacts of reactions among NO, NO_2, and O_x

5. SELECTION OF MONITORING SITES FOR PHOTOCHEMICAL POLLUTANTS

5.1. General Principles of Site Selection

The selection of a specific monitoring site requires four major steps:

1. Identify the purpose to be served by the monitoring
2. Identify the monitoring site type(s) that will best serve the purpose
3. Identify the general locations where the monitoring sites should be placed
4. Identify specific monitoring sites.

The major categories of monitoring purpose have been listed and that list includes most of the possible outcomes of Step 1 above.

Step 2 can be accomplished by the use of Table 7, which is a matrix of the monitoring purposes enumerated earlier and the station types given in Table 6. The combinations of monitoring purpose and site type that apply to the different pollutants are indicated in Table 7. This table is designed to serve as a guide to matching purpose with appropriate site type.

The most important principle in the selection of specific sites is that the effects from individual sources, other than those of interest in source-oriented monitoring, should be minimal. The concept of representativity implies homogeneity. The regions of strong gradients need to be identified and avoided. In general, the undesirable areas are likely to be associated with strong individual sources or sinks, so the problem becomes one of locating the important sources or sinks and assessing their effects on the surroundings. The importance of a source or sink depends on the scale to be represented and on the concentrations prevailing in the region of interest. In rural areas with low pollutant concentrations, a certain source or sink may distort conditions appreciably, but that same source or sink in a city neighborhood might go virtually unnoticed because of the generally higher concentrations and the greater density of similar sources and sinks.

5.2. Site Selection Procedures

The following discussions of site selection have been kept specific. The justification for the recommendations are given in Section 6 of this report.

5.2.1. Nonmethane Hydrocarbons

5.2.1.1. General

Figure 8 presents the step-by-step procedure for selecting nonmethane hydrocarbon monitoring sites. The selection of monitoring sites begins with the assembly of the necessary background information. The first box of the flow chart in Figure 8 gives examples of information that is valuable in the site selection process. Maps and aerial photographs of the region provide information concerning the location of streets, commercial areas, and the nature of the regional topography. If an emissions inventory has not already been compiled for the region, it will probably be necessary to compile one. The Environmental Protection Agency (1974) has prepared a guide for assembling emissions inventories. The methodology for calculating air pollutant emissions factors has been described in detail in another EPA (1975) document. This latter document is subject to frequent revisions and the issuance of supplements and addenda. The user should use the most recent methodologies.

Population densities are important because they identify regions of great public exposure and the distribution of population density in an area approximates the distributed source emissions. If one knows the total emissions in the region arising from, say, space heating, then it is reasonable to distribute these emissions according to the distribution of population. Population and housing data are available for the census tracts within 241 Standard Metropolitan Statistical Areas (SMSA). Figure 9 from one of these Bureau of the Census (1972) documents shows the size of some tracts. In general, tracts are smaller in areas of dense population than in less

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Table 7

MONITORING PURPOSES AND SITE TYPES

Purpose	Site Types					
	Urban/Regional			Neighborhood		
	Important Reactant	Important Product	General	Source	General	Traffic Effects or Middle Scale
1. Determine compliance with Air Quality Standards						
Federal Primary	NMHC, NO_2	O_x	NO_2, O_x	NO_2	NO_2, O_x	O_x, NO_2
State and Local	NMHC, NO_2	O_x	NO_2, O_x	NO_2	NO_2, O_x	O_x, NO_2
2. Provide data for preparation of environmental impact statements	NMHC, NO, NO_2		NMHC, O_x, NO_2	NMHC, NO, NO_2	NMHC, NO_2, O_x	NMHC, NO_2, O_x
3. Evaluate the contribution to observed concentration of specific sources, by type and location of emissions						
Natural				NMHC,		
Man-made				NMHC, NO, NO_2		O_x, NO, NO_2
4. Provide information on chemical reactions involving the pollutants and their reactivity	NMHC, NO, NO_2	NO_2, O_x	NMHC, NO, NO_2 O_x	NO, NO_2, NMHC	NO, NO_2, O_x, NMHC	NMHC, NO_2, NO, O_x
5. Provide a basis for describing processes that affect pollutant concentration	NMHC, NO, NO_2	NO_2, O_x	NMHC, NO, NO_2	NMHC, NO_2, NO		O_x, NO_2, NO
6. Test monitoring equipment			NMHC, NO, NO_2, O_x		NMHC, NO NO_2, O_x	
7. Evaluate results of control measures						
Local				NMHC, NO_2		NO_2, O_x
Larger			NMHC, NO_2			
8. Determine long-term trends			NMHC, NO_2, O_x, NO		NMHC, NO_2, NO, O_x	
9. Provide a basis for invoking short-term or emergency control measures	NO_2, NMHC	O_x, NO_2	NO_2, O_x, NMHC	NO, NO_2	NO_2, O_x, NMHC	
10. Evaluate effects of human exposure to the pollutants			NO_2, O_x	NO_2	NO_2, O_x	NO_2, O_x
11. Determine effects on plants, animals, and materials			NO_2, O_x		NO_2, O_x	NO, NO_2, O_x
12. Assess representativeness of existing monitoring sites			NMHC, NO_2, O_x, NO		NMHC, NO_2 NO, O_x	

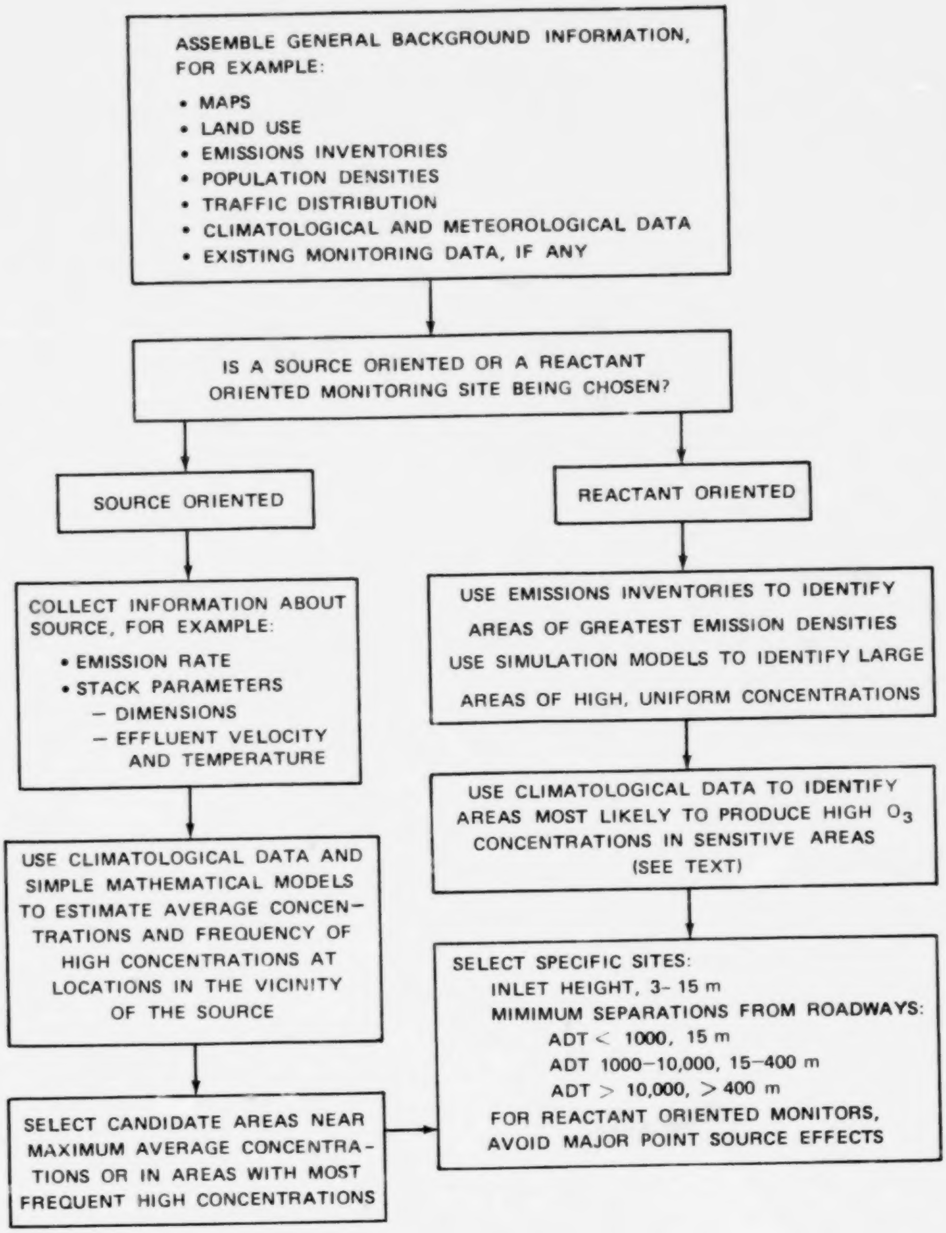
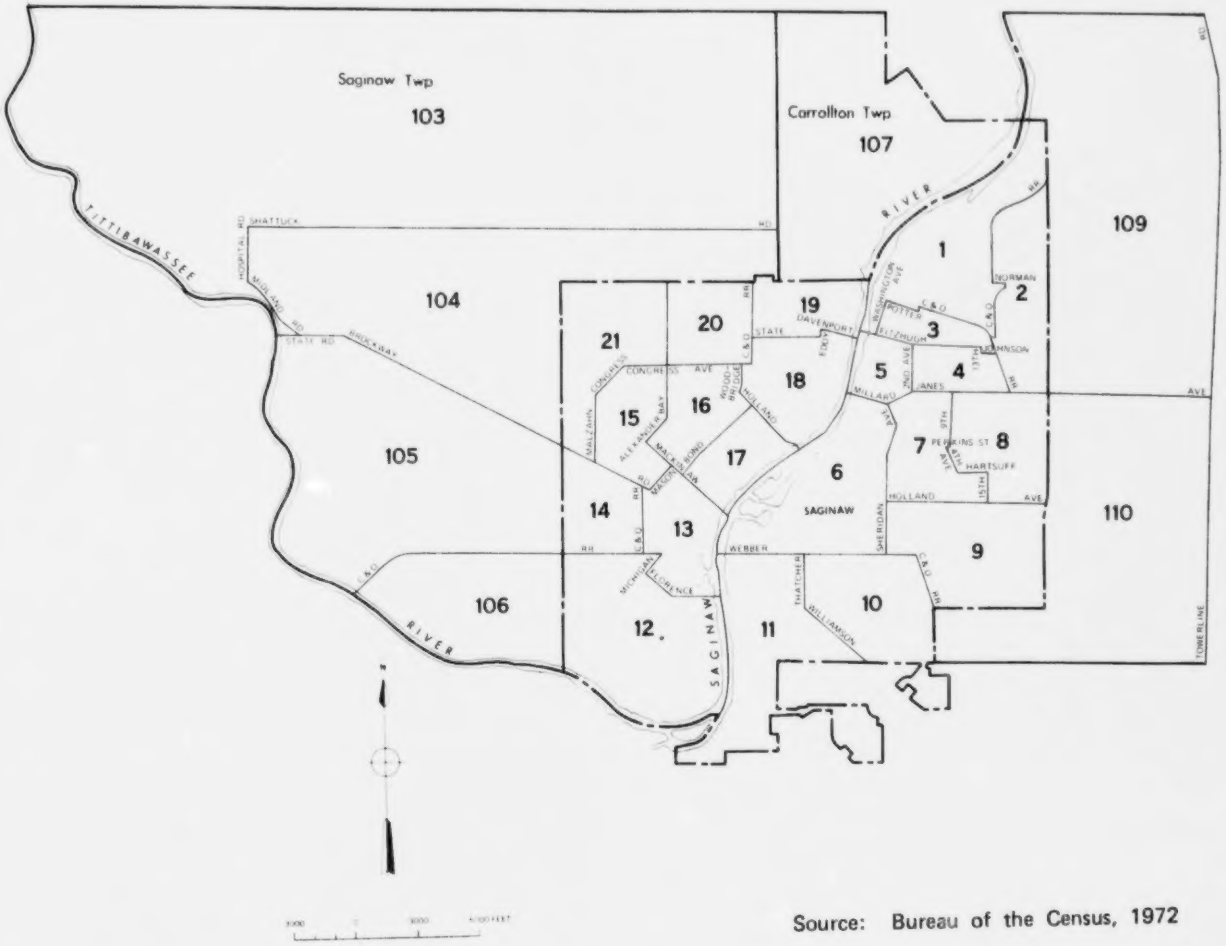

ASSEMBLE GENERAL BACKGROUND INFORMATION, FOR EXAMPLE:
• MAPS
• LAND USE
• EMISSIONS INVENTORIES
• POPULATION DENSITIES
• TRAFFIC DISTRIBUTION
• CLIMATOLOGICAL AND METEOROLOGICAL DATA
• EXISTING MONITORING DATA, IF ANY
IS A SOURCE ORIENTED OR A REACTANT ORIENTED MONITORING SITE BEING CHOSEN?
SOURCE ORIENTED
REACTANT ORIENTED
COLLECT INFORMATION ABOUT SOURCE, FOR EXAMPLE:
• EMISSION RATE
• STACK PARAMETERS
– DIMENSIONS
– EFFLUENT VELOCITY AND TEMPERATURE
USE CLIMATOLOGICAL DATA AND SIMPLE MATHEMATICAL MODELS TO ESTIMATE AVERAGE CONCENTRATIONS AND FREQUENCY OF HIGH CONCENTRATIONS AT LOCATIONS IN THE VICINITY OF THE SOURCE
SELECT CANDIDATE AREAS NEAR MAXIMUM AVERAGE CONCENTRATIONS OR IN AREAS WITH MOST FREQUENT HIGH CONCENTRATIONS
USE EMISSIONS INVENTORIES TO IDENTIFY AREAS OF GREATEST EMISSION DENSITIES
USE SIMULATION MODELS TO IDENTIFY LARGE AREAS OF HIGH, UNIFORM CONCENTRATIONS
USE CLIMATOLOGICAL DATA TO IDENTIFY AREAS MOST LIKELY TO PRODUCE HIGH O_3 CONCENTRATIONS IN SENSITIVE AREAS (SEE TEXT)
SELECT SPECIFIC SITES:
INLET HEIGHT, 3- 15 m
MIMIMUM SEPARATIONS FROM ROADWAYS:
ADT < 1000, 15 m
ADT 1000–10,000, 15–400 m
ADT > 10,000, > 400 m
FOR REACTANT ORIENTED MONITORS, AVOID MAJOR POINT SOURCE EFFECTS

FIGURE 8 SCHEMATIC DIAGRAM OF PROCEDURE FOR SELECTING NMHC MONITORING SITES


Saginaw Twp
103
Carrollton Twp
107
109
110
104
105
106
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
SAGINAW
TITTIBAWASSEE
RIVER
SAGINAW
RIVER
SHATTUCK RD
HOSPITAL RD
MIDLAND RD
STATE RD
BROCKWAY
CONGRESS AVE
MALZAHN
ALEXANDER WAY
MACKINAW
BOND
MASON
WOOD-BRIDGE
HOLLAND
STATE
DAVENPORT
EDDY
WASHINGTON AVE
POTTER
FITZHUGH
C&O
NORMAN
JOHNSON
13TH
2ND AVE
JANES
MILLARD
9TH
PERKINS ST
8TH AVE
HARTSUFF
15TH
HOLLAND AVE
SHERIDAN
WEBBER
THATCHER
WILLIAMSON
MICHIGAN
FLORENCE
RR
AVE
TOWERLINE
RD
5000 0 5000 10000 FEET

Source: Bureau of the Census, 1972

FIGURE 9 EXAMPLE OF CENSUS TRACTS

densely populated areas. The Office of Air Quality Planning and Standards of EPA has prepared computer programs that will apportion area source emissions from the National Emissions Data Systems (NEDS; see e.g., Bosch, 1975) into gridded areas according to population. Valuable information concerning major point sources in the area are also available from NEDS. Figure 10 gives an example of point source emission information from NEDS.

Traffic data are useful as bases for an emissions inventory, especially if they can be converted into emissions estimates for different grid squares within the region of interest. A computer program is available for converting traffic data from the Federal Highway Administration or other sources into a gridded inventory for the pollutants, carbon monoxide, oxides of nitrogen, and nonmethane hydrocarbons. This program (Ludwig et al., 1977) can also be used to calculate concentrations arising from traffic emissions for specified weather conditions and times of day.

Climatological and meteorological data are essential to the proper selection of monitoring sites. One kind of climatological summary that is of particular use is the frequency distribution of wind speed and direction. This information comes either as a tabulated joint frequency distribution like that shown in Table 8 (an example of material that is available from the National Climatic Center in Asheville, North Carolina) or as a wind rose, another form in which the same kind of information is often presented. Examples of wind roses are shown in Figure 11 from the National Climatic Atlas (National Oceanic and Atmospheric Administration, 1968). More specific summaries might be useful for selecting reactant-oriented monitoring sites. Appendix B to this report contains a simple computer program that can be used with data from the National Climatic Center to determine the joint frequencies of wind speed and direction during periods of high temperatures. The stratification of the data on the basis of temperature is justified because the photochemical reactions tend to be more pronounced during such periods.

Finally, the site selection process should use any existing monitoring data or special studies that are available for the region of interest. If a body of data exists from reasonably well located monitoring stations, then those data will be more useful than modeling for determining the locations of areas of maximum concentrations within the region. Special studies can also provide useful information concerning the variability of concentrations in time and space. Special studies often focus on important kinds of air pollution events and will provide useful guidance for the location of monitors that will characterize similar events in the future.

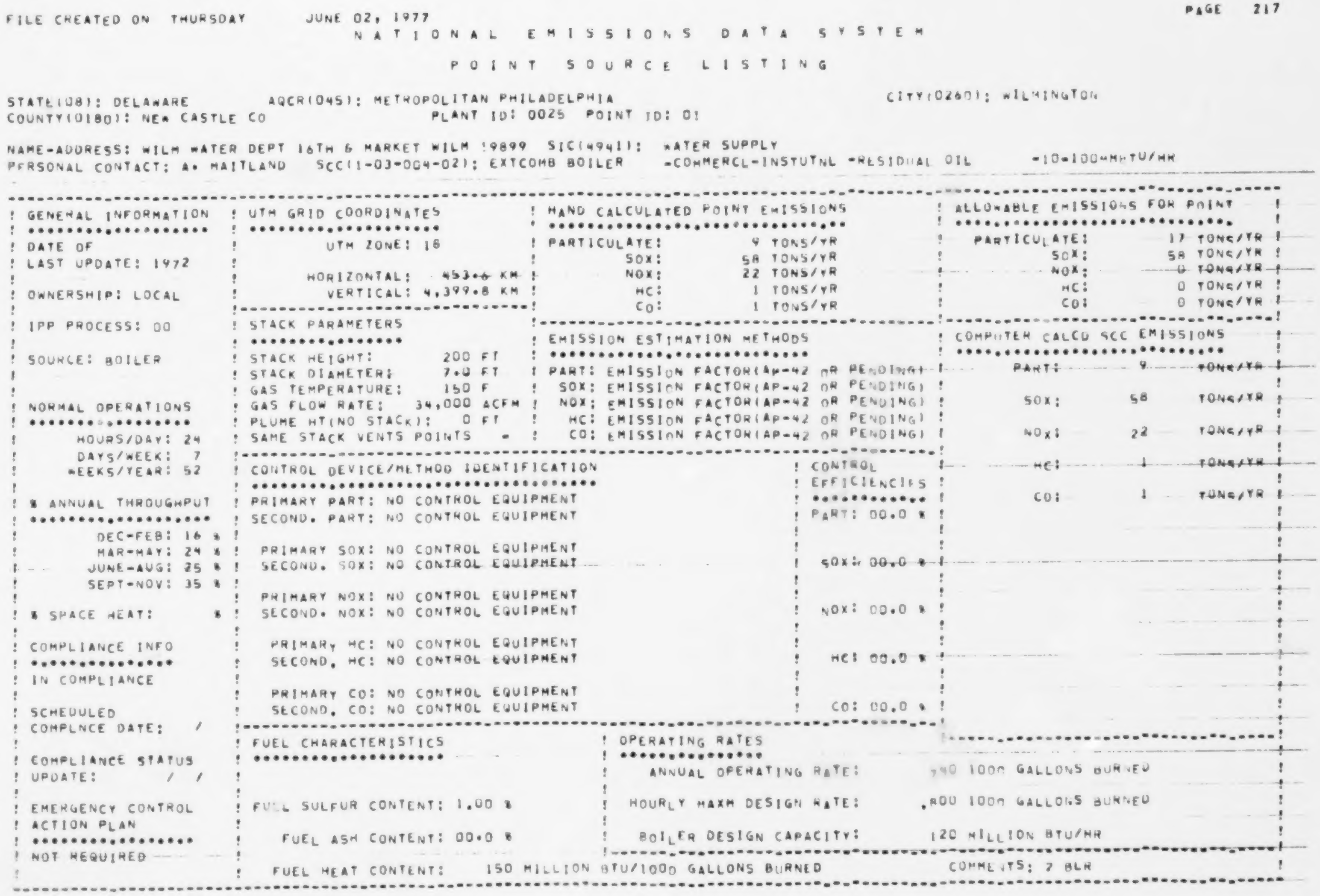
Ludwig and Kealoha (1975) in their report on the selection of sites for carbon monoxide monitoring presented several appendices to help identify sources of information that are useful to the site selection process.

After the background material has been assembled, a decision must be made regarding whether or not the monitor is to be the source-oriented or the reactant-oriented type. The two branches in the flow chart in Figure 8 show the procedures for the selection of these two different types of sites.

5.2.1.2. Source-Oriented Monitors

In general, source-oriented monitoring of NMHC is less important than reactant-oriented monitoring, but there will be occasions when the effects and impacts of a specific hydrocarbon source are of interest. A discussion of the identification of areas important to source-oriented monitoring can also be useful for identifying areas that should be avoided in locating other types of monitors.

Figure 8 shows that source characteristics are important in selecting source-oriented sites. It would be wise to check NEDS information independently to ensure that there have not been changes in the operating characteristics of the source and that the information in NEDS has been properly archived. The next step is to combine the source information with climatological information to identify areas of greatest impact. Source-oriented monitoring applies to large point sources, generally elevated. The impact of such an elevated point source can be defined in different ways.



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FILE CREATED ON  THURSDAY      JUNE 02, 1977                                                                    PAGE  217
                           N A T I O N A L   E M I S S I O N S   D A T A   S Y S T E M

                                          P O I N T   S O U R C E   L I S T I N G

STATE(08): DELAWARE        AQCR(045): METROPOLITAN PHILADELPHIA                         CITY(0260): WILMINGTON
COUNTY(0180): NEW CASTLE CO                     PLANT ID: 0025  POINT ID: 01

NAME-ADDRESS: WILM WATER DEPT 16TH & MARKET WILM 19899  SIC(4941):  WATER SUPPLY
PERSONAL CONTACT: A. MAITLAND   SCC(1-03-004-02); EXTCOMB BOILER    -COMMERCL-INSTUTNL -RESIDUAL OIL      -10-100-MMBTU/HR

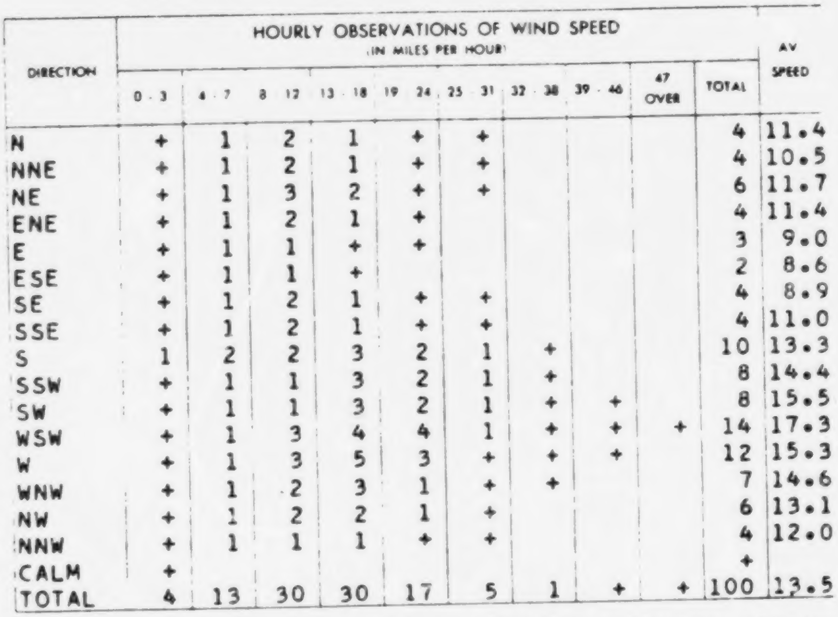
------------------------------------------------------------------------------------------------------------------------------
! GENERAL INFORMATION   ! UTM GRID COORDINATES          ! HAND CALCULATED POINT EMISSIONS          ! ALLOWABLE EMISSIONS FOR POINT      !
! ********************* ! ********************          ! ******************************           ! ***************************        !
! DATE OF               !          UTM ZONE: 18         ! PARTICULATE:           9 TONS/YR         !    PARTICULATE:         17 TONS/YR !
! LAST UPDATE: 1972     !                               !         SOX:          58 TONS/YR         !            SOX:         58 TONS/YR !
!                       !       HORIZONTAL:    453.6 KM !         NOX:          22 TONS/YR         !            NOX:          0 TONS/YR !
! OWNERSHIP: LOCAL      !         VERTICAL: 4,399.8 KM  !          HC:           1 TONS/YR         !             HC:          0 TONS/YR !
!                       !-------------------------------!          CO:           1 TONS/YR         !             CO:          0 TONS/YR !
! IPP PROCESS: 00       ! STACK PARAMETERS              !------------------------------------------!------------------------------------!
!                       ! ****************              ! EMISSION ESTIMATION METHODS              ! COMPUTER CALCD SCC EMISSIONS       !
! SOURCE: BOILER        ! STACK HEIGHT:        200 FT   ! **************************               ! ****************************       !
!                       ! STACK DIAMETER:      7.0 FT   ! PART: EMISSION FACTOR(AP-42 OR PENDING)  !       PART:      9      TONS/YR    !
!                       ! GAS TEMPERATURE:     150 F    !  SOX: EMISSION FACTOR(AP-42 OR PENDING)  !                                    !
! NORMAL OPERATIONS     ! GAS FLOW RATE:   34,000 ACFM  !  NOX: EMISSION FACTOR(AP-42 OR PENDING)  !       SOX:     58      TONS/YR    !
! *****************     ! PLUME HT(NO STACK):    0 FT   !   HC: EMISSION FACTOR(AP-42 OR PENDING)  !                                    !
!     HOURS/DAY: 24     ! SAME STACK VENTS POINTS   -   !   CO: EMISSION FACTOR(AP-42 OR PENDING)  !       NOX:     22      TONS/YR    !
!     DAYS/WEEK:  7     !--------------------------------------------------------------------------!                                    !
!    WEEKS/YEAR: 52     ! CONTROL DEVICE/METHOD IDENTIFICATION                 ! CONTROL           !        HC:      1      TONS/YR    !
!                       ! ***********************************                  ! EFFICIENCIES      !                                    !
! % ANNUAL THROUGHPUT   ! PRIMARY PART: NO CONTROL EQUIPMENT                   ! ************      !        CO:      1      TONS/YR    !
! ********************* ! SECOND. PART: NO CONTROL EQUIPMENT                   ! PART: 00.0 %      !                                    !
!        DEC-FEB: 16 %  !                                                      !                   !                                    !
!        MAR-MAY: 24 %  !  PRIMARY SOX: NO CONTROL EQUIPMENT                   !                   !                                    !
!       JUNE-AUG: 25 %  !  SECOND. SOX: NO CONTROL EQUIPMENT                   !   SOX: 00.0 %     !                                    !
!       SEPT-NOV: 35 %  !                                                      !                   !                                    !
!                       !  PRIMARY NOX: NO CONTROL EQUIPMENT                   !                   !                                    !
! % SPACE HEAT:       % !  SECOND. NOX: NO CONTROL EQUIPMENT                   !   NOX: 00.0 %     !                                    !
!                       !                                                      !                   !                                    !
! COMPLIANCE INFO       !   PRIMARY HC: NO CONTROL EQUIPMENT                   !                   !                                    !
! *************         !   SECOND, HC: NO CONTROL EQUIPMENT                   !    HC: 00.0 %     !                                    !
! IN COMPLIANCE         !                                                      !                   !                                    !
!                       !   PRIMARY CO: NO CONTROL EQUIPMENT                   !                   !                                    !
! SCHEDULED             !   SECOND, CO: NO CONTROL EQUIPMENT                   !    CO: 00.0 %     !                                    !
! COMPLNCE DATE:   /    !--------------------------------------------------------------------------!------------------------------------!
!                       ! FUEL CHARACTERISTICS               ! OPERATING RATES                                                          !
! COMPLIANCE STATUS     ! ********************               ! ***************                                                          !
! UPDATE:        /  /   !                                    !    ANNUAL OPERATING RATE:        790 1000 GALLONS BURNED               !
!                       !                                    !                                                                          !
! EMERGENCY CONTROL     ! FUEL SULFUR CONTENT: 1.00 %        !  HOURLY MAXM DESIGN RATE:        .800 1000 GALLONS BURNED              !
! ACTION PLAN           !                                    !                                                                          !
! *****************     !   FUEL ASH CONTENT: 00.0 %         !   BOILER DESIGN CAPACITY:        120 MILLION BTU/HR                    !
! NOT REQUIRED          !                                    !--------------------------------------------------------------------------!
!                       !  FUEL HEAT CONTENT:    150 MILLION BTU/1000 GALLONS BURNED              COMMENTS: 2 BLR                       !
------------------------------------------------------------------------------------------------------------------------------
```

FIGURE 10 EXAMPLE OF NEDS POINT SOURCE EMISSION DATA

Table 8

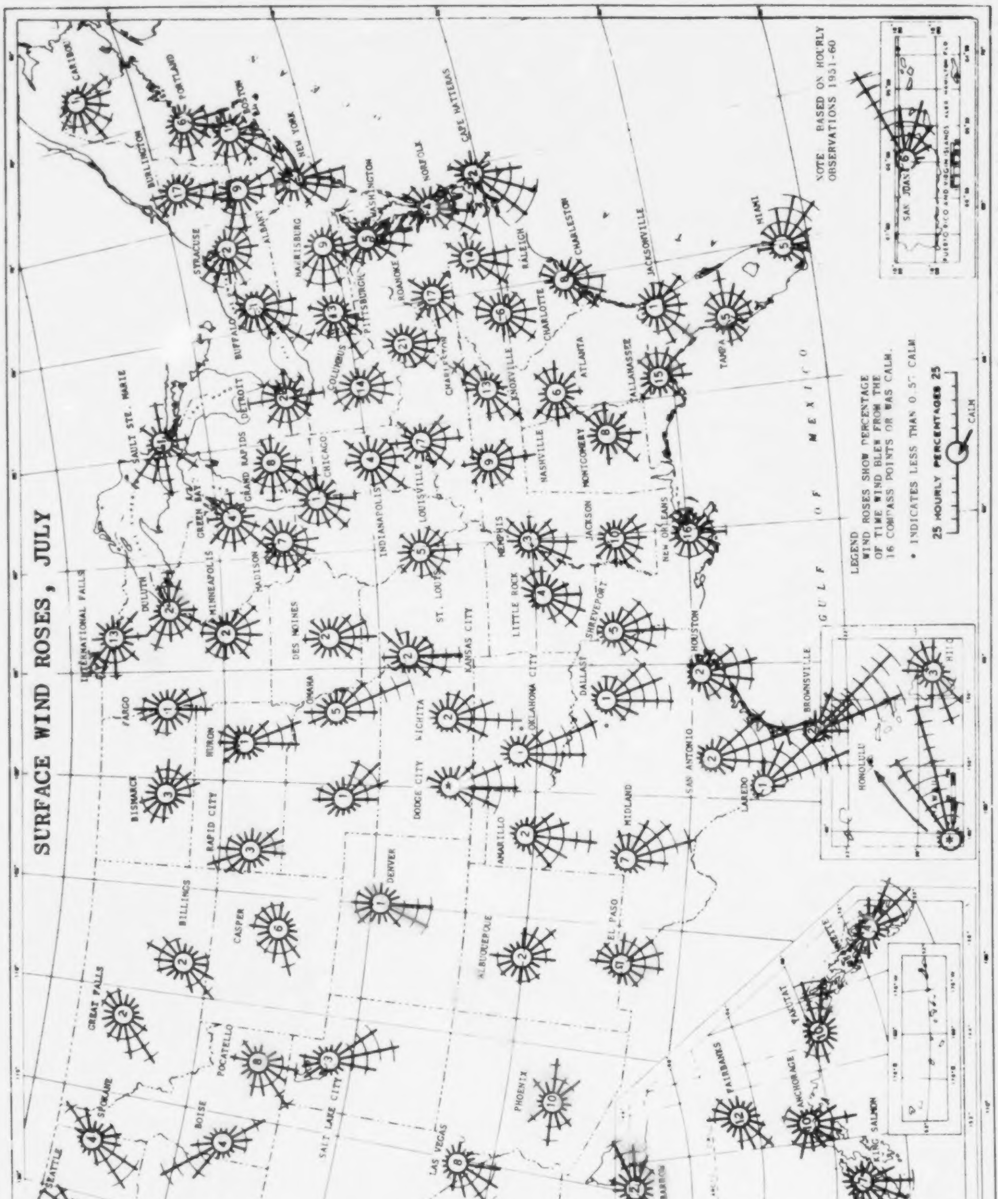
EXAMPLE OF A STATISTICAL WIND SUMMARY FROM THE
NATIONAL CLIMATIC CENTER
(Asheville, North Carolina)

PERCENTAGE FREQUENCIES OF WIND DIRECTION AND SPEED:



DIRECTION	HOURLY OBSERVATIONS OF WIND SPEED (IN MILES PER HOUR)										AV SPEED
	0 - 3	4 - 7	8 - 12	13 - 18	19 - 24	25 - 31	32 - 38	39 - 46	47 OVER	TOTAL	
N	+	1	2	1	+	+				4	11.4
NNE	+	1	2	1	+	+				4	10.5
NE	+	1	3	2	+	+				6	11.7
ENE	+	1	2	1	+					4	11.4
E	+	1	1	+	+					3	9.0
ESE	+	1	1	+						2	8.6
SE	+	1	2	1	+	+				4	8.9
SSE	+	1	2	1	+	+				4	11.0
S	1	2	2	3	2	1	+			10	13.3
SSW	+	1	1	3	2	1	+			8	14.4
SW	+	1	1	3	2	1	+	+		8	15.5
WSW	+	1	3	4	4	1	+	+	+	14	17.3
W	+	1	3	5	3	+	+	+		12	15.3
WNW	+	1	2	3	1	+	+			7	14.6
NW	+	1	2	2	1	+				6	13.1
NNW	+	1	1	1	+	+				4	12.0
CALM	+									+	
TOTAL	4	13	30	30	17	5	1	+	+	100	13.5

Source: National Climatic Center
Asheville, N. C.



SURFACE WIND ROSES, JULY
NOTE: BASED ON HOURLY OBSERVATIONS 1951-60
LEGEND
WIND ROSES SHOW PERCENTAGE OF TIME WIND BLEW FROM THE 16 COMPASS POINTS OR WAS CALM.
* INDICATES LESS THAN 0.5% CALM
25 HOURLY PERCENTAGES 25
CALM
GULF OF MEXICO
TATOOSH ISLAND
SEATTLE
PORTLAND
SPOKANE
GREAT FALLS
BOISE
POCATELLO
MEDFORD
RENO
SAN FRANCISCO
FRESNO
LOS ANGELES
LAS VEGAS
SALT LAKE CITY
PHOENIX
BILLINGS
CASPER
DENVER
ALBUQUERQUE
EL PASO
BISMARCK
RAPID CITY
FARGO
HURON
OMAHA
DODGE CITY
WICHITA
AMARILLO
OKLAHOMA CITY
MIDLAND
DALLAS
SAN ANTONIO
LAREDO
BROWNSVILLE
HOUSTON
INTERNATIONAL FALLS
DULUTH
MINNEAPOLIS
DES MOINES
KANSAS CITY
ST. LOUIS
LITTLE ROCK
SHREVEPORT
MADISON
GREEN BAY
SAULT STE. MARIE
GRAND RAPIDS
CHICAGO
INDIANAPOLIS
LOUISVILLE
MEMPHIS
JACKSON
NEW ORLEANS
DETROIT
COLUMBUS
NASHVILLE
MONTGOMERY
KNOXVILLE
ATLANTA
TALLAHASSEE
CHARLESTON
BUFFALO
PITTSBURGH
ROANOKE
CHARLOTTE
JACKSONVILLE
TAMPA
MIAMI
SYRACUSE
HARRISBURG
WASHINGTON
RALEIGH
NORFOLK
CAPE HATTERAS
ALBANY
NEW YORK
BURLINGTON
BOSTON
PORTLAND
CARIBOU
ALASKA
BARROW
NOME
FAIRBANKS
ANCHORAGE
YAKUTAT
KING SALMON
COLD BAY
HONOLULU
HILO
SAN JUAN
PUERTO RICO AND VIRGIN ISLANDS

Source: National Oceanic & Atmospheric Administration, 1968

FIGURE 11 SURFACE WIND ROSES, JULY

A model of some sort will provide a mechanism by which the source characteristics and the climatological information can be combined to define areas of important impact. Several simple computerized models are available for determining the areas of maximum average impact from a point source. These models include the Climatological Dispersion Model (Busse and Zimmerman, 1973) and the model presented by Ludwig, Kealoha, and Shelar (1977). Estimates can also be made without using a computer. The greatest long-term impact is likely to be associated with the most frequent combinations of wind direction, speed, and atmospheric stability. These joint frequencies can be obtained from the National Climatic Center from the output of their STAR computer program. An example of the STAR program output is shown in Figure 12.

The direction from the source to the receptor site will be the downwind direction for the most frequent combination of stability, wind speed, and wind direction. The best distance at which to locate the monitoring site can be estimated by calculating the plume rise for the stability and wind speed of concern. The wind speed at the top of the stack is likely to differ from that measured at ground height, typically 10 meters. Beals (1971) has given information that can be used to correct the wind speed observed near ground level to that at stack height; the required corrections are summarized in Figure 13 . Briggs (1969) gives equations for determining plume rise. Once the height of the plume is known for the most common combination of stability, wind speed, and wind direction, then the distance to the area of maximum concentration for that case can be estimated from graphs like those given by Turner (1969). Figures 14 and 15 are two of Turner's graphs. The ordinate in these graphs represents concentration normalized for emission rate, Q, and wind speed, u.

The location of the maximum concentration is of great importance to the site selection problem, but its absolute magnitude is of less importance. Figures 14 and 15 show that the concentration rises rapidly with distance to a maximum and then falls gradually beyond the maximum. The location of the site should probably be somewhat beyond the distance where the maximum concentration is predicted. This allows some margin for error by putting the monitor in a region of relatively small gradients rather than near the strong gradients toward the source from the maximum.

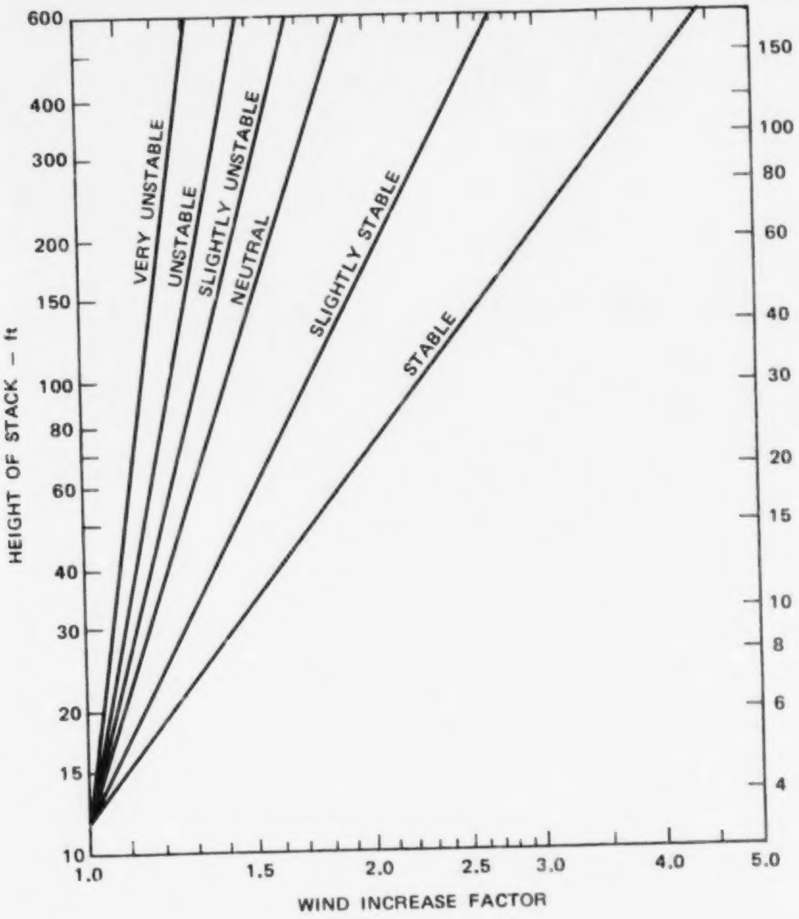
The highest short-term concentration from an elevated source is most likely to occur at ground level under extremely unstable conditions, such unstable conditions are unlikely to occur during the 6:00 - 9:00 a.m. period specified as being of interest in the air quality guidelines, because surface heating in the early morning is insufficient to produce strong instability. Therefore, the slightly unstable and moderately unstable conditions which are possible during this time period are more important. The wind directions and wind speeds occurring most frequently with slightly unstable and moderately unstable conditions can be determined from the output of the STAR program. The effective plume rise should be calculated for the most frequent wind speeds. Figure 14 can be used as a basis for locating the distance from the source to the region of maximum NMHC concentrations under slightly unstable conditions. The direction for the best monitoring site will be the most frequent direction occurring during slightly unstable conditions. If several directions commonly occur under such atmospheric stability conditions, then it may be necessary to have more than one site.

Since the purpose for locating source-oriented monitoring sites is to determine the impact of a specific source, it will generally be necessary to have another site nearby to characterize the "background" conditions in the area. A reactant-oriented site located in a direction from the source that is opposite that of the source-oriented site will serve the purpose. An effort should also be made to avoid locating the source-oriented site in an area that is impacted by other major point sources. If this cannot be done, then measurements of wind speed and direction at the sampling site will be essential so that it will be possible to determine when the source of interest is affecting on the monitor. Wind speed and direction measurements will allow the data to be interpreted so that the impacts of different major sources can be differentiated.

```
          SEA= MAM                  RELATIVE FREQUENCY DISTRIBUTION          STATION =13882 CHATTANOOGA, TN 24 OBS 1960-64

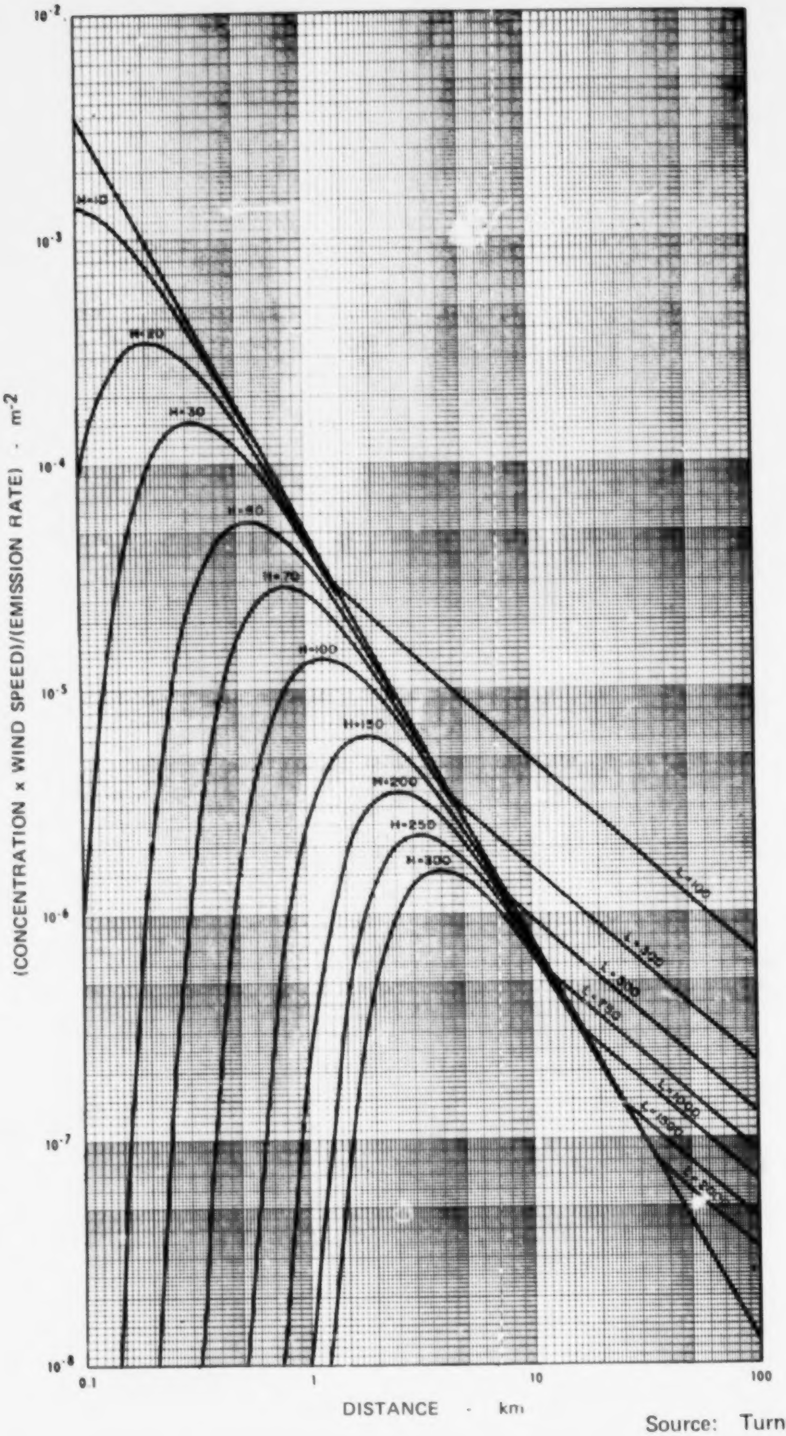
                                                 SPEED(KTS)
DIRECTION       0 - 3        4 - 6        7 - 10       11 - 16      17 - 21   GREATER THAN 21        TOTAL
      N       0.000912     0.002719     0.004079     0.007614     0.000725     0.000000           0.016048
    NNE       0.000800     0.004169     0.006888     0.010605     0.000634     0.000000           0.023096
     NE       0.000731     0.002900     0.002175     0.003535     0.000181     0.000000           0.009523
    ENE       0.000385     0.001813     0.000634     0.000544     0.000000     0.000000           0.003376
      E       0.000069     0.001269     0.000453     0.000091     0.000000     0.000000           0.001882
    ESE       0.000245     0.000997     0.000544     0.000091     0.000000     0.000000           0.001877
     SE       0.000919     0.001088     0.001178     0.000453     0.000091     0.000000           0.003729
    SSE       0.001449     0.003807     0.005348     0.006707     0.000997     0.000272           0.018579
      S       0.001386     0.006163     0.017765     0.026194     0.004260     0.000363           0.056131
    SSW       0.000655     0.003263     0.006526     0.014411     0.001903     0.000181           0.026940
     SW       0.000696     0.002266     0.003625     0.004713     0.000725     0.000091           0.012117
    WSW       0.000280     0.001631     0.002175     0.006617     0.001722     0.000997           0.013422
      W       0.000160     0.001178     0.001994     0.005962     0.001088     0.000906           0.011308
    WNW       0.000135     0.000725     0.003807     0.010333     0.003625     0.001269           0.019894
     NW       0.000422     0.000725     0.001269     0.005529     0.002538     0.001178           0.011661
    NNW       0.000547     0.001269     0.003988     0.009426     0.002357     0.000363           0.017949
TOTAL         0.009789     0.035983     0.062449     0.112843     0.020847     0.005620
RELATIVE FREQUENCY OF OCCURRENCE OF  D  STABILITY  = 0.247530
RELATIVE FREQUENCY OF CALMS DISTRIBUTED ABOVE WITH  D  STABILITY  =  0.002357
                          (NEUTRAL / DAY)
```

FIGURE 12 EXAMPLE OF STAR PROGRAM OUTPUT



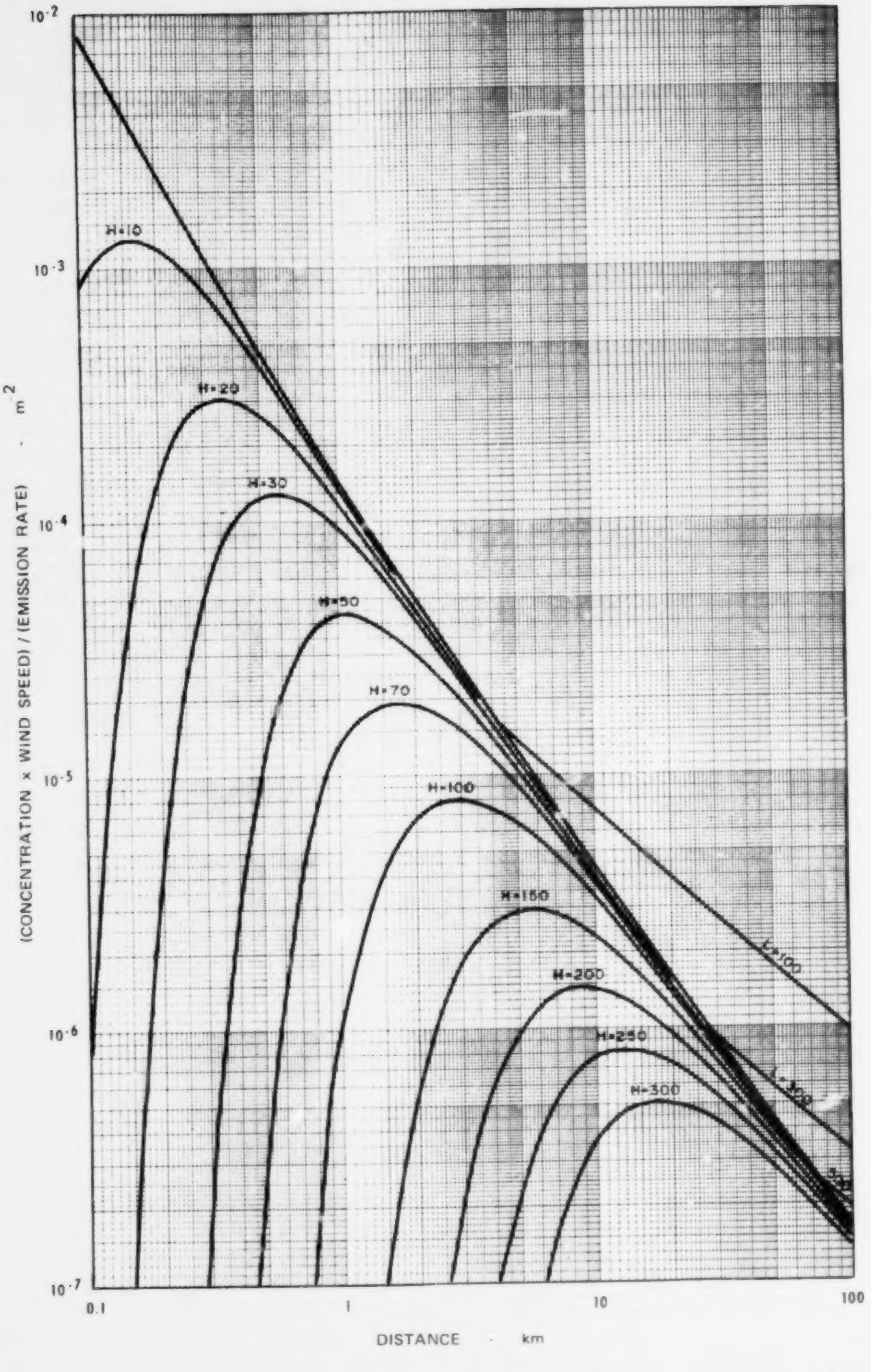
SA-1567-9

FIGURE 13 VARIATIONS OF WIND SPEED WITH HEIGHT AND STABILITY



Source: Turner, 1969

FIGURE 14 NORMALIZED GROUND LEVEL CONCENTRATIONS FROM AN ELEVATED SOURCE FOR SLIGHTLY UNSTABLE CONDITIONS



Source: Turner, 1969

FIGURE 15 NORMALIZED GROUND LEVEL CONCENTRATIONS FROM AN ELEVATED SOURCE FOR NEUTRAL STABILITY

After the general area for the source-oriented monitor has been identified, it is necessary to select a specific location within that area. The inlet should be about 3 to 15 meters in height and well removed from ground-level sources such as roadways or large space heating or process emissions of hydrocarbons. Specific siting requirements are discussed further in the next section.

5.2.1.3. Reactant-Oriented Monitors

The right-hand branch of the flow chart in Figure 8 shows the steps necessary to select reactant-oriented NMHC monitoring sites. The first step is to use the emissions inventories to identify areas where emission densities are greatest. This may be sufficient, but it is preferable to take the next step and use the simulation model in combination with the emissions inventory and climatological information, to estimate the concentration distribution throughout the area. The Climatological Dispersion Model (Busse and Zimmerman, 1973) is well suited for this purpose. The candidate areas for locating the monitoring sites will be found in those areas where high concentrations are expected. The best areas will be relatively large and have reasonably uniform concentration throughout.

It is reasonable to select areas for monitoring NMHC that are most likely to be associated with high oxidant concentrations in sensitive areas. The first step in finding where such areas are located is the identification of those meteorological conditions most likely to associated with the production of large concentrations of oxidants. The approach taken here is to derive wind statistics for those hours when high temperatures prevail. Figure 16 and Table 9 are examples of the output that can be derived from the computer program in Appendix B. The wind directions associated with light winds and high temperatures define the critical travel directions for the measured hydrocarbons. In general, the oxidant concentrations will begin to build up within a few tens of kilometers downwind of the sources. Each of the areas determined to be subject to relatively high hydrocarbon concentrations should be examined to see if it lies upwind of any particularly sensitive areas. Those high hydrocarbon areas that are upwind of sensitive areas during conditions likely to produce high oxidant values are the best places for NMHC monitors.

The monitoring site should be well removed from local sources. Figure 8 specifies minimum separations between the monitor and roadways with different levels of average daily traffic (ADT). The site should be well away from other major ground level sources of hydrocarbons, e.g. gasoline stations, dry cleaners, surface coating operations, refineries, or petrochemical complexes. No exact minimum separation can be specified for these kinds of sources, but the discussions in Section 6 of this report should provide the reader with sufficient understanding so that the minimum separation can be calculated for a specific source.

The inlet at the monitoring site should be placed between about 3 and 15 meters above ground level and about a meter above the support surface. It should be separated from any surrounding obstacles by about twice the height of the obstacle above the inlet.

5.2.2. Oxides of Nitrogen

5.2.2.1. General

NO is not a criteria pollutant. However, the role of NO in the formation and destruction of ozone is too important to be ignored. Also, NO is the pollutant initially emitted from most of the sources of concern. The importance of NO demands that the siting requirements for monitoring it be considered, but the major emphasis still remains on the criteria pollutant, NO_2. In the following sections procedures are given for siting NO_2 monitors for general purposes, for reactant-oriented purposes, and for product-oriented purposes. General monitoring has been considered to be that which would be used to characterize population exposure. Product-oriented monitoring is similar, but the emphasis on NO_2's role as a product leads to the selection of locations in high concentration areas. Finally, reactant-oriented monitoring of NO and NO_2 concentrations has objectives similar to those discussed above in connection with reactant-oriented hydrocarbon monitoring.

LEGEND & NOTES

1. Wind speed (mps)

2. Frequency scale (%)

3. Inner circle area of rose is proportional to frequency (%) of calm conditions (1 mps or less)

4. Angle of wind rose lims reflect direction from which wind is blowing

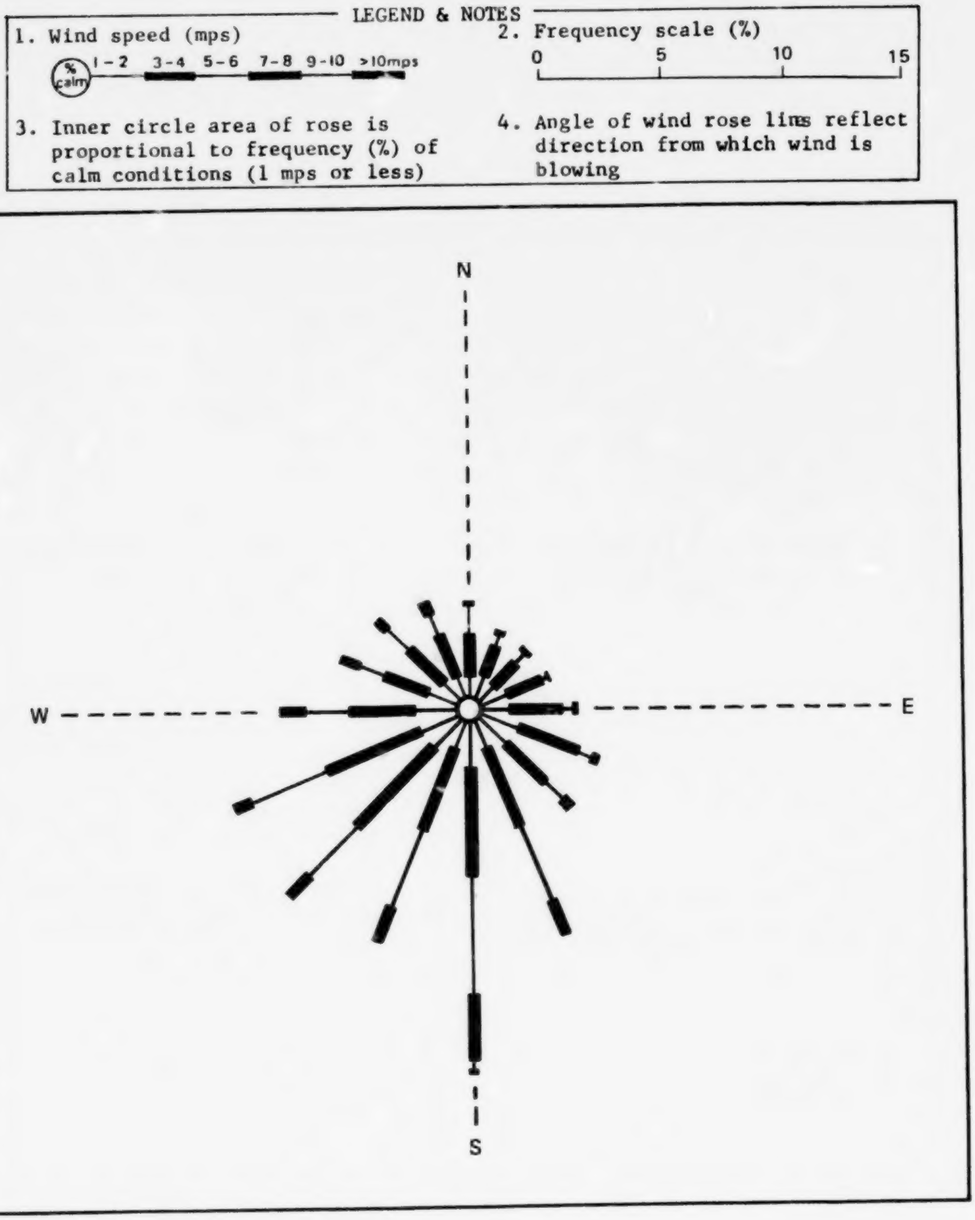


FIGURE 16 ST.LOUIS WIND ROSE FOR DAYTIME HOURS WHEN THE TEMPERATURE EXCEEDED 80^{O}F.
Data represent observations from 1 January 1960 through 31 December 1974.

Table 9

TABULATED WIND STATISTICS FOR DAYTIME HOURS FOR ST. LOUIS, WHEN TEMPERATURE EXCEEDED 80°F

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FREQUENCIES OF OCCURRENCES

DIRECT/CATEGORY	1.0-2.0	3.0-4.0	5.0-6.0	7.0-8.0	9.0-10.0	.GT.11.0	TOTAL
NNE	45.0	64.0	24.0	2.0	0.0	0.0	135.0
NE	38.0	63.0	29.0	2.0	0.0	0.0	132.0
ENE	49.0	76.0	14.0	1.0	0.0	0.0	140.0
E	54.0	99.0	29.0	2.0	0.0	0.0	184.0
ESE	75.0	125.0	41.0	2.0	0.0	0.0	243.0
SE	68.0	106.0	57.0	12.0	3.0	1.0	247.0
SSE	52.0	169.0	161.0	58.0	7.0	1.0	448.0
S	80.0	220.0	232.0	128.0	22.0	2.0	684.0
SSW	51.0	175.0	165.0	63.0	6.0	1.0	461.0
SW	74.0	220.0	136.0	38.0	10.0	2.0	480.0
WSW	80.0	198.0	162.0	35.0	5.0	0.0	480.0
W	87.0	122.0	91.0	32.0	6.0	2.0	340.0
WNW	65.0	88.0	52.0	26.0	8.0	1.0	240.0
NW	48.0	90.0	63.0	18.0	4.0	0.0	223.0
NNW	42.0	89.0	49.0	14.0	2.0	1.0	197.0
N	40.0	81.0	55.0	5.0	0.0	0.0	181.0
COLUMN TOTAL	948.0	1985.0	1360.0	438.0	73.0	11.0	4815.0

NO. OF CALM OBSERVATIONS: 46.0

PERCENTAGE OF OCCURRENCES

DIRECT/CATEGORY	1.0-2.0	3.0-4.0	5.0-6.0	7.0-8.0	9.0-10.0	.GT.11.0	TOTAL
NNE	.9	1.3	.5	.0	0.0	0.0	2.8
NE	.8	1.3	.6	.0	0.0	0.0	2.7
ENE	1.0	1.6	.3	.0	0.0	0.0	2.9
E	1.1	2.0	.6	.0	0.0	0.0	3.8
ESE	1.5	2.6	.8	.0	0.0	0.0	5.0
SE	1.4	2.2	1.2	.2	.1	.0	5.1
SSE	1.1	3.5	3.3	1.2	.1	.0	9.2
S	1.5	4.5	4.8	2.6	.5	.0	14.1
SSW	1.0	3.6	3.4	1.3	.1	.0	9.5
SW	1.5	4.5	2.8	.8	.2	.0	9.9
WSW	1.6	4.1	3.3	.7	.1	0.0	9.9
W	1.8	2.5	1.9	.7	.1	.0	7.0
WNW	1.3	1.8	1.1	.5	.2	.0	4.9
NW	1.0	1.9	1.3	.4	.1	0.0	4.6
NNW	.9	1.8	1.0	.3	.0	.0	4.1
N	.8	1.7	1.1	.1	0.0	0.0	3.7
COLUMN TOTAL	19.5	40.8	28.0	9.0	1.5	.2	99.1
						Calms	.9
						Total	100.0

5.2.2.2. Source-Oriented Monitors

Figure 17 is a flow chart presenting the steps necessary to the selection of an appropriate monitoring site that can be used for assessing the impact of large sources of oxides of nitrogen. The similarities with that part of Figure 8 that deals with source-oriented hydrocarbon monitoring are obvious. The process begins with the acquisition of the background information including the characteristics of the source that is being studied. The source strengths and the stack parameters are of primary importance. These data, along with climatological data, particularly the output of the STAR program, will be required to determine where concentration maxima are most likely to be found. If there are existing monitoring data for NO and NO_2 in the area, then they should be used in the selection process. Maps and emissions inventories are required to identify susceptible neighborhoods and other sources of NO_x that might interfere with the measurements.

The NAAQS are concerned with annual mean concentrations of NO_2, so the emphasis in site selection will be in finding those areas where long-term averages are apt to be the highest. However, it appears that a short term standard may be adopted in the future, so that possibility must also be considered. A simple model like that given by Ludwig, Kealoha and Shelar (1977) or the CDM (Busse and Zimmerman, 1973) or Turner's (1969) workbook should serve to define such areas. Such models are likely to overestimate the concentrations of NO_2 that will be observed because they deal with total oxides of nitrogen rather than the single compound NO_2. Nevertheless, it is expected that the maximum NO_2 concentrations will occur in approximately the same locations as the maximum NO_x concentrations. The best course would be to locate the site somewhat beyond the expected point of maximum NO_x to allow somewhat more time for the formation of NO_2.

If one is selecting a site to determine whether the annual standard is violated, then "maximum" refers to long-term average concentrations. If the monitoring is done to assess compliance with a short-term standard such as EPA may adopt and some states already have (e.g., California has an one-hour standard of 250 ppb), then the most likely areas for the occurrence of violations of this standard should be identified. In general, short term maxima occur with more unstable atmospheric conditions and are closer to the source. For example, a comparison of Figures 14 and 15 shows that for any given stack height, the ground level concentrations will be greater, and closer to the stack, for the unstable conditions (Figure 14) than for the neutral conditions (Figure 15).

Once the general areas for the site have been selected, a more specific site must be located. It should be near the area of anticipated maximum NO_2 influence, but removed from interferences so that its measurements will accurately characterize the influence of the source being studied. The site should be away from heavy traffic. The flow chart (Figure 17) recommends minimum separation distances from streets and roadways with different levels of average daily traffic (ADT). It is not certain, but buildings, trees, and other obstacles may scavenge NO_2. To avoid this kind of interference, the monitor should be away from such obstacles. Two or three times the height of the obstacle above the monitor is recommended. For similar reasons, a probe inlet along a vertical wall is undesirable because air moving along that wall may be subject to removal mechanisms.

Air from a fairly tall, large point source will be reasonably well mixed by the time it reaches ground level. Therefore, vertical gradients are not apt to be large in the first few meters above the ground and a wide range of probe heights will be acceptable; 3 to 15 meters is suggested. If the height of the source under study is comparable to this height, then the gradients may be large and any monitoring that is done to assess compliance wih the NAAQS or to evaluate health effects should be done nearer to the breathing zone, i.e. about 3 meters.

Supplemental measurements will be valuable to the interpretation of the air quality data collected at the stations. In source-oriented monitoring, anemometers will provide information that allows the analyst to determine when emissions from the stack have impinged on the

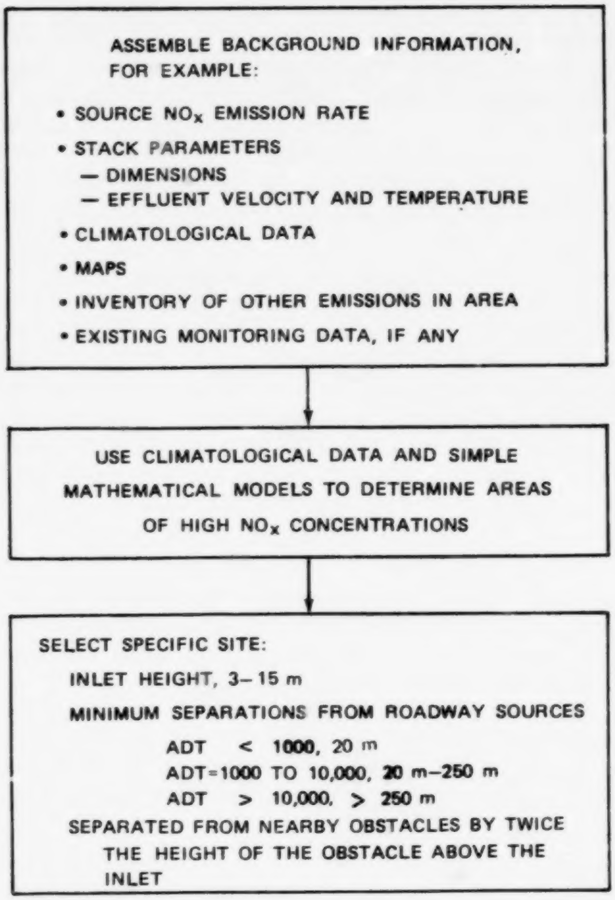

ASSEMBLE BACKGROUND INFORMATION, FOR EXAMPLE:
• SOURCE NO_x EMISSION RATE
• STACK PARAMETERS
— DIMENSIONS
— EFFLUENT VELOCITY AND TEMPERATURE
• CLIMATOLOGICAL DATA
• MAPS
• INVENTORY OF OTHER EMISSIONS IN AREA
• EXISTING MONITORING DATA, IF ANY
USE CLIMATOLOGICAL DATA AND SIMPLE MATHEMATICAL MODELS TO DETERMINE AREAS OF HIGH NO_x CONCENTRATIONS
SELECT SPECIFIC SITE:
INLET HEIGHT, 3–15 m
MINIMUM SEPARATIONS FROM ROADWAY SOURCES
ADT < 1000, 20 m
ADT=1000 TO 10,000, 20 m–250 m
ADT > 10,000, > 250 m
SEPARATED FROM NEARBY OBSTACLES BY TWICE THE HEIGHT OF THE OBSTACLE ABOVE THE INLET

FIGURE 17 SCHEMATIC DIAGRAM OF PROCEDURE FOR SELECTING SITES FOR SOURCE ORIENTED NO AND NO_2 MONITORING

monitoring site. Records of the stack operation, particularly as they affect the emissions, can also be used to evaluate the impact of that particular source on its surroundings.

5.2.2.3. Neighborhood and Regional Scale Monitors

Figure 18 shows procedures to select sites for neighborhood and regional scale NO_x monitoring. As always, the process begins with the acquisition of background information. Then it must be decided whether the emphasis of the monitoring will be on oxides of nitrogen as a product, primarily NO_2, or as total oxides of nitrogen serving as reactants in the photochemical process. If the concern is for oxides of nitrogen in their role as reactants, then the site selection process is similar to that suggested for hydrocarbon monitors. A simple diffusion model can be used to identify neighborhoods where maximum NO_x concentrations are to be expected, especially during those seasons when photochemical activity is likely to be at its greatest. If modeling cannot be done, then the next best approach is to identify those neighborhoods with maximum NO_x emissions. The high concentration areas can be examined to see if populated areas or areas that might be susceptible to harmful effects from photochemical pollution are found downwind. "Downwind" refers to wind directions that are most frequent during weather conditions conducive to photochemical activity. It has been found (Meyer, et al., 1976; Ludwig, Reiter, et al., 1977) that the factor most associated with high ozone concentrations, and hence greatest photochemical activity, is air temperature. Therefore, a wind rose based on those hours with high temperatures should serve to identify the most likely wind directions during periods of photochemical pollutant formation. Figure 16 presents an example of such a wind rose derived from hourly wind observations when the temperature exceeded 80°F in St. Louis, Missouri. Other temperatures could be chosen. It appears that photochemical ozone formation becomes most important above about 20°C (68°F).

As Figure 18 shows, the final site selection for neighborhood scale monitoring of NO and NO_2 concentrations will find a location where local NO_x sources have minimal influence on the observation. The identification of areas where there will be high concentrations from a point source has already been discussed. Figure 18 suggests minimum separations between the monitor and nearby roadways (as a function of average daily traffic) to keep the influence of traffic sources at a minimum. The recommended inlet height is in the range from 3 to 15 meters. If the site is properly chosen so that the data collected there will represent neighborhood conditions, then the oxides of nitrogen should be reasonably well mixed and the height of the inlet will not be very critical.

When the interest is in NO_2, as it will be for monitoring related to health effects or the NAAQS, then the site should be product-oriented . There are two scales of measurement that are of interest, neighborhood and regional. Selecting neighborhood scale, product-oriented monitoring sites for NO_2 begins in the same way as the procedure for selecting reactant-oriented sites. Areas of major NO_x emissions are identified and the most frequent wind directions for periods of photochemical activity are defined. Then, prospective siting areas will be chosen downwind of the major source areas. Observations suggest (see Section 6) that NO_2 concentrations are likely to fall off rather rapidly outside the urbanized area. Therefore, the best locations for characterizing high NO_2 concentrations will be within the city. For long term average concentrations, the maxima tend to be displaced downwind of the major source areas. The displacement is the distance traveled by the air in an hour or two under normal wind conditions. This will usually be a few kilometers. The highest one-hour average concentrations of NO_2 tend to be very close to the areas of greatest NO_x emissions. Thus, a site to ascertain compliance with a short term standard would be located in an area of maximum emissions. In both cases, monitoring for short or long term standards, residential neighborhoods will be most important, because the assessment of compliance with air quality standards relates to public health.

For either short or long term monitoring, the measurements should be representative of a reasonably large, neighborhood-sized area. Therefore, the location must be away from NO_x sources, either major point sources or traffic sources. An inlet height of 3 to 15 meters is

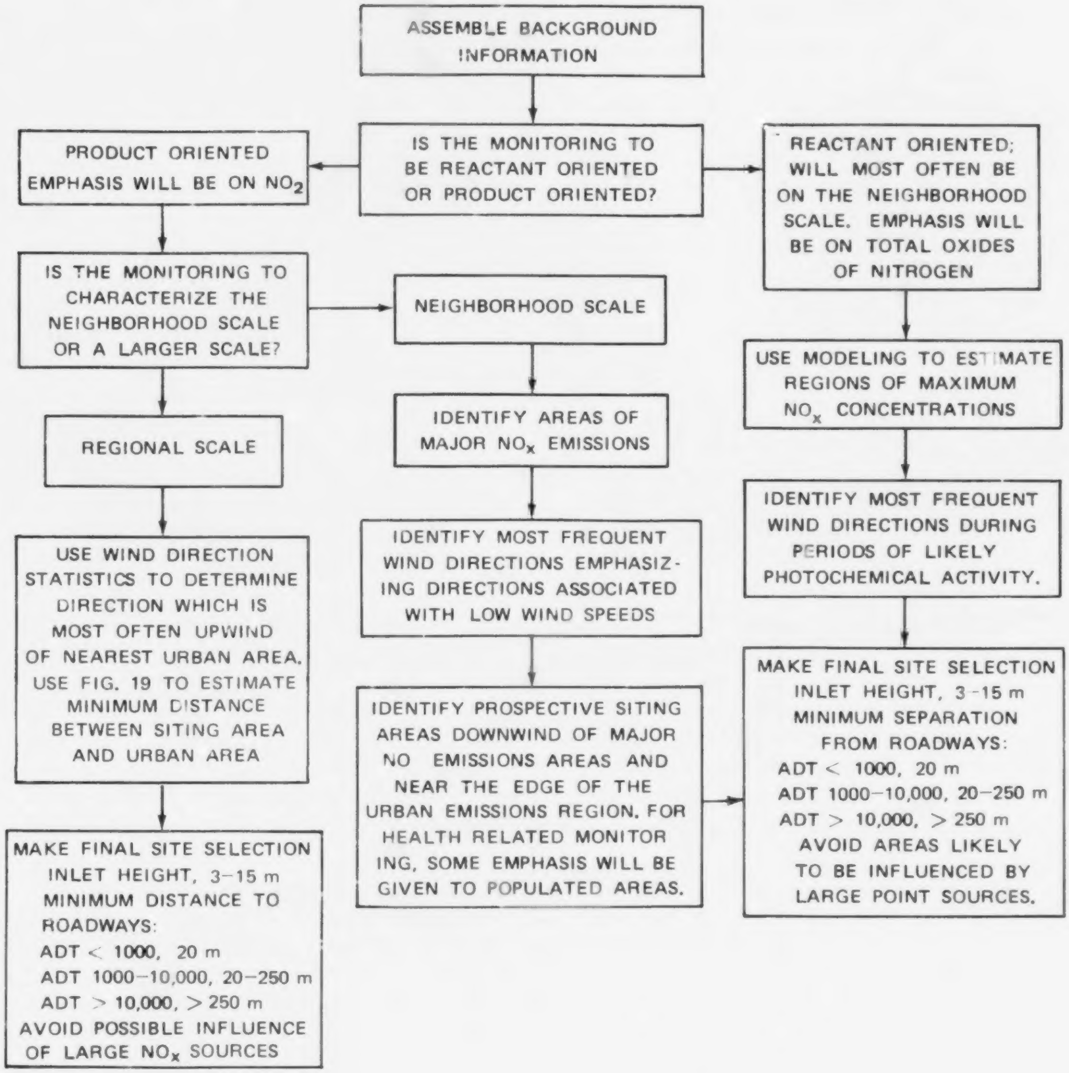

ASSEMBLE BACKGROUND INFORMATION
IS THE MONITORING TO BE REACTANT ORIENTED OR PRODUCT ORIENTED?
PRODUCT ORIENTED EMPHASIS WILL BE ON NO_2
REACTANT ORIENTED; WILL MOST OFTEN BE ON THE NEIGHBORHOOD SCALE. EMPHASIS WILL BE ON TOTAL OXIDES OF NITROGEN
IS THE MONITORING TO CHARACTERIZE THE NEIGHBORHOOD SCALE OR A LARGER SCALE?
NEIGHBORHOOD SCALE
USE MODELING TO ESTIMATE REGIONS OF MAXIMUM NO_x CONCENTRATIONS
REGIONAL SCALE
IDENTIFY AREAS OF MAJOR NO_x EMISSIONS
IDENTIFY MOST FREQUENT WIND DIRECTIONS DURING PERIODS OF LIKELY PHOTOCHEMICAL ACTIVITY.
USE WIND DIRECTION STATISTICS TO DETERMINE DIRECTION WHICH IS MOST OFTEN UPWIND OF NEAREST URBAN AREA. USE FIG. 19 TO ESTIMATE MINIMUM DISTANCE BETWEEN SITING AREA AND URBAN AREA
IDENTIFY MOST FREQUENT WIND DIRECTIONS EMPHASIZING DIRECTIONS ASSOCIATED WITH LOW WIND SPEEDS
IDENTIFY PROSPECTIVE SITING AREAS DOWNWIND OF MAJOR NO EMISSIONS AREAS AND NEAR THE EDGE OF THE URBAN EMISSIONS REGION. FOR HEALTH RELATED MONITORING, SOME EMPHASIS WILL BE GIVEN TO POPULATED AREAS.
MAKE FINAL SITE SELECTION INLET HEIGHT, 3-15 m MINIMUM SEPARATION FROM ROADWAYS: ADT < 1000, 20 m ADT 1000–10,000, 20–250 m ADT > 10,000, > 250 m AVOID AREAS LIKELY TO BE INFLUENCED BY LARGE POINT SOURCES.
MAKE FINAL SITE SELECTION INLET HEIGHT, 3–15 m MINIMUM DISTANCE TO ROADWAYS: ADT < 1000, 20 m ADT 1000–10,000, 20–250 m ADT > 10,000, > 250 m AVOID POSSIBLE INFLUENCE OF LARGE NO_x SOURCES

FIGURE 18 SCHEMATIC DIAGRAM OF PROCEDURE FOR SELECTING NEIGHBORHOOD AND REGIONAL SCALE MONITORING SITES FOR NO AND NO_2

desirable and it should not be along a vertical wall where destructive processes might affect the measurements. Wherever possible the site should be away from obstructions. The rule of thumb mentioned earlier, i.e. separation from an obstruction by a distance of two times the obstruction heights above the monitor, applies to both the reactant- and product-oriented, neighborhood scale NO_x and NO_2 monitoring sites.

The procedure for selecting regional scale monitoring sites has been placed in the product-oriented branch of the flow chart in Figure 18. This is because most of the sources of NO_x are in the urban areas. Regional monitoring will measure the concentrations of NO and NO_2 after they have been modified by chemical reactions in the atmosphere and have become "products". There is some ambiguity in this approach; there is evidence (e.g. Singh, Ludwig and Johnson, 1977) that when oxides of nitrogen are present in remote regions, they can initiate oxidant-forming reactions. However, in regional scale monitoring of NO and NO_2, the distinction between product and reactant makes little difference to the site selection process.

Inasmuch as the monitoring purpose for this kind of site will usually be served best by a site that has only minimal urban influence, the best areas will be those which are least frequently downwind of an area of strong emissions. A wind rose applicable to the region will be used to determine which direction is most frequent. Figure 19 shows the distance at which the Office of Air Quality Planning and Standards (OAQPS, 1977) has estimated urban influences on NO_x concentrations fall to about 7 ppb. The value 7 ppb was chosen to be slightly above the limits of detection of current instrumentation. Figure 20 (from OAQPS, 1977) provides a convenient representation of those areas within which regional monitoring of NO_2 is probably above "background" concentrations.

After the general areas for the regional scale monitoring have been identified, the specific site will be chosen to minimize influences of NO_x sources. It is important to avoid the influence of large point sources such as power plants that might be located in rural areas. The methodology for identifying areas of major point source impact (already discussed) can be used to identify areas to be avoided. Wind monitoring at the site could identify instances of point source impact.

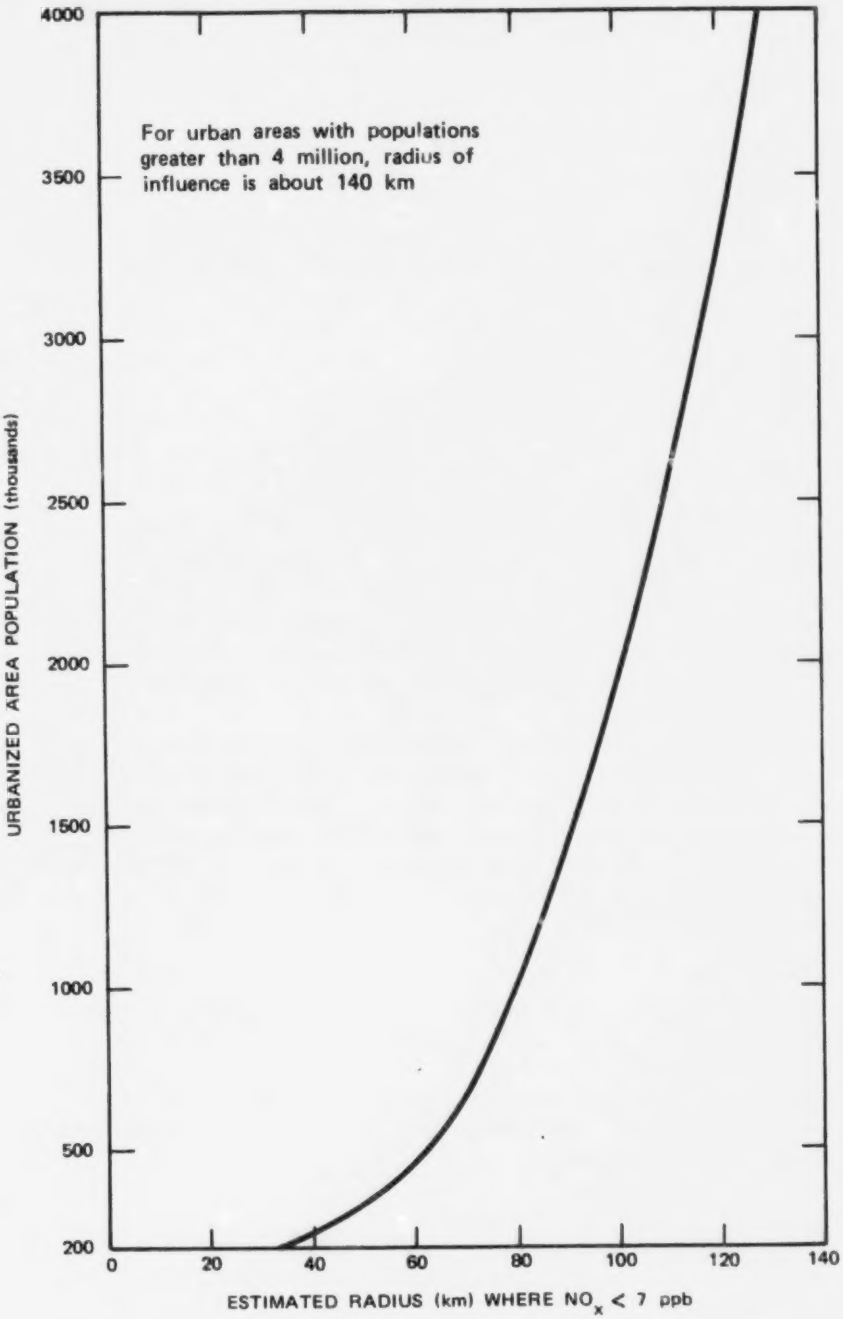
Inlet heights of 3 to 15 meters are recommended for the reasons discussed in connection with neighborhood monitoring sites. A monitoring site should be removed from obstacles. The separation should be greater than required for neighborhood monitoring sites because the influences of obstacles should be reduced to especially low levels, commensurate with the lower levels of NO_x concentrations in the nonurban areas. The inlet for a regional monitor should be at least a meter or two above the instrument shelter and should not be located so that it protrudes from a wall of that shelter.

5.2.3. Oxidants

Two types of neighborhood scale monitoring sites are considered. One will be used to characterize typical concentrations in the urban region and the other to measure maximum, or near-maximum, concentrations in the region. A regional site for typical concentrations in the area surrounding the city is also discussed. Figure 21 summarizes the procedure for selecting the important kinds of sites. It reemphasizes the importance of collecting background information before site selection procedes.

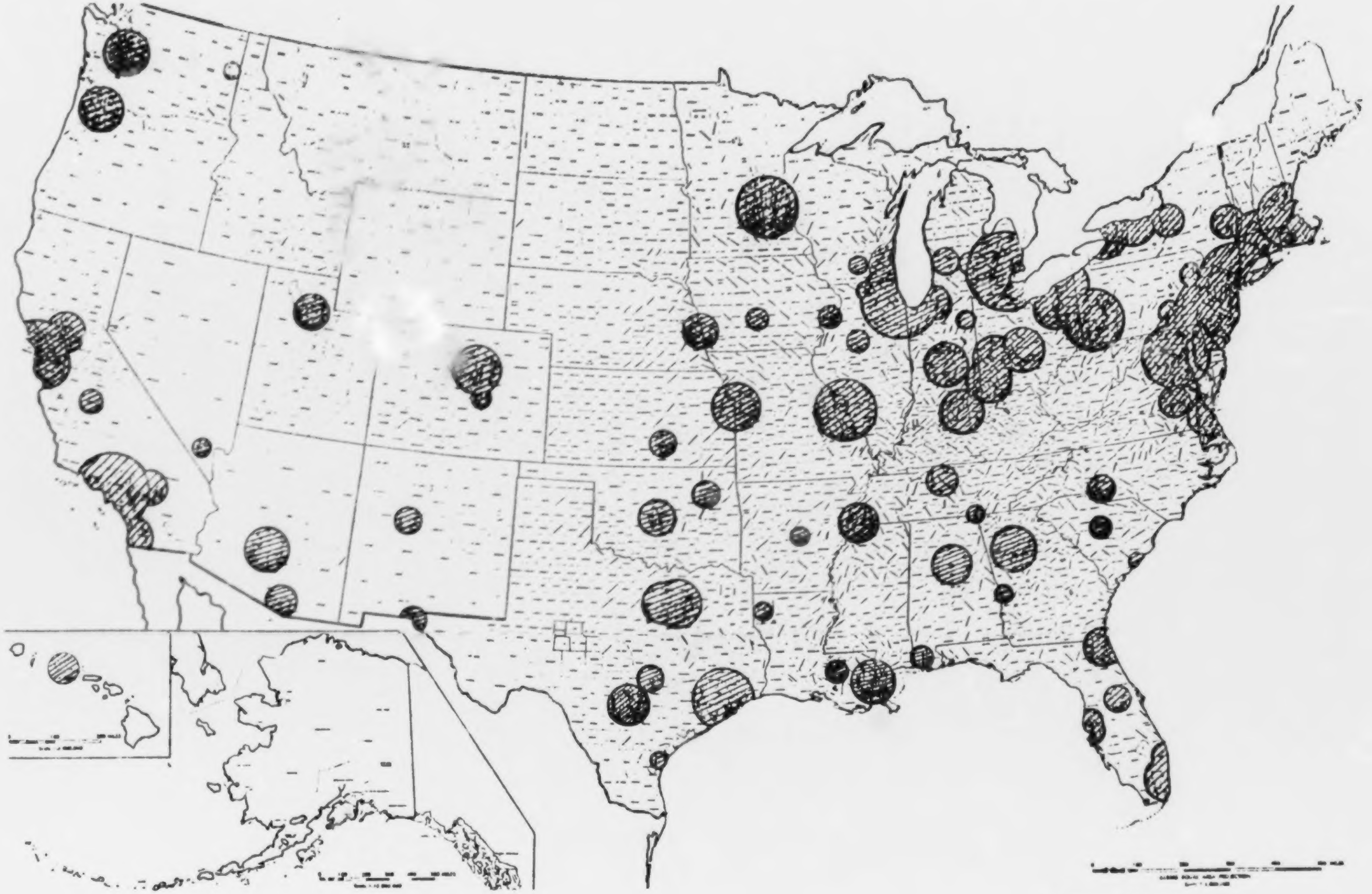
5.2.3.1. Regional Scale Monitors

After the background information has been assembled, the next step in selecting a regional scale monitor is to determine what direction is most associated with those meteorological conditions that are conducive to photochemical formation of ozone. As noted before, temperature serves as a good indicator of the propensity for ozone formation. Prospective areas for regional scale background monitoring of ozone would be found in a direction that is upwind of the urban area for those winds which are frequently associated with high temperatures. For example, Figure 16 shows that winds from directions between south-southeast and west are common in St. Louis when temperatures exceed 80°F so the best areas for regional background



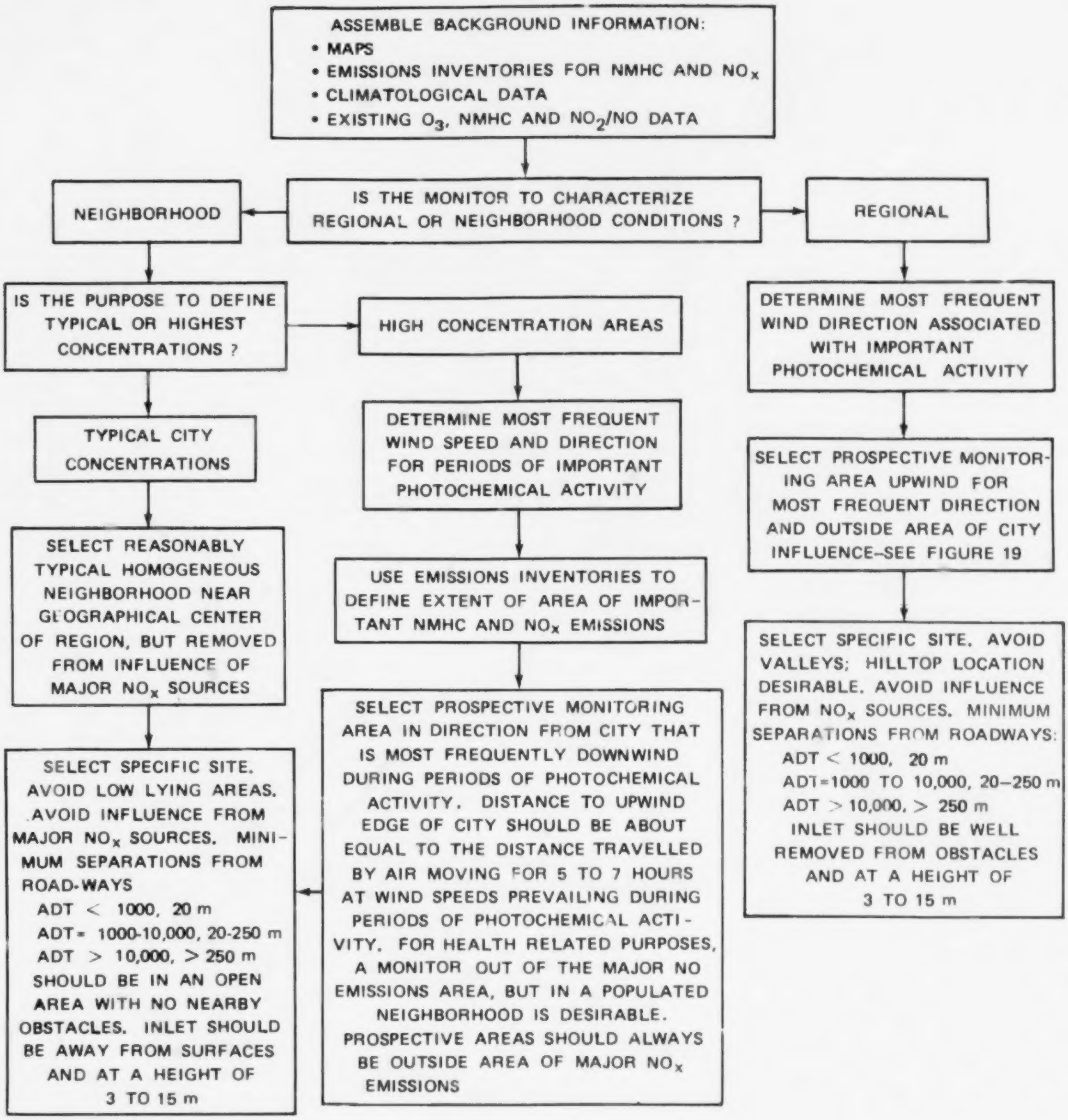
Source: OAQPS, 1977

FIGURE 19 ESTIMATED RADIUS AT WHICH NO AND NO_2 CONCENTRATIONS FALL BELOW 7 ppb, AS A FUNCTION OF METROPOLITAN POPULATION



Source: OAQPS, 1977

FIGURE 20 ESTIMATED AREAS BEYOND WHICH NO_X CONCENTRATIONS ARE LIKELY TO BE LESS THAN 7 ppb



ASSEMBLE BACKGROUND INFORMATION:
- MAPS
- EMISSIONS INVENTORIES FOR NMHC AND NO_x
- CLIMATOLOGICAL DATA
- EXISTING O_3, NMHC AND NO_2/NO DATA

IS THE MONITOR TO CHARACTERIZE REGIONAL OR NEIGHBORHOOD CONDITIONS ?

IS THE PURPOSE TO DEFINE TYPICAL OR HIGHEST CONCENTRATIONS ?

SELECT REASONABLY TYPICAL HOMOGENEOUS NEIGHBORHOOD NEAR GEOGRAPHICAL CENTER OF REGION, BUT REMOVED FROM INFLUENCE OF MAJOR NO_x SOURCES

SELECT SPECIFIC SITE. AVOID LOW LYING AREAS. AVOID INFLUENCE FROM MAJOR NO_x SOURCES. MINIMUM SEPARATIONS FROM ROAD-WAYS
ADT < 1000, 20 m
ADT = 1000-10,000, 20-250 m
ADT > 10,000, > 250 m
SHOULD BE IN AN OPEN AREA WITH NO NEARBY OBSTACLES. INLET SHOULD BE AWAY FROM SURFACES AND AT A HEIGHT OF 3 TO 15 m

DETERMINE MOST FREQUENT WIND SPEED AND DIRECTION FOR PERIODS OF IMPORTANT PHOTOCHEMICAL ACTIVITY

USE EMISSIONS INVENTORIES TO DEFINE EXTENT OF AREA OF IMPORTANT NMHC AND NO_x EMISSIONS

SELECT PROSPECTIVE MONITORING AREA IN DIRECTION FROM CITY THAT IS MOST FREQUENTLY DOWNWIND DURING PERIODS OF PHOTOCHEMICAL ACTIVITY. DISTANCE TO UPWIND EDGE OF CITY SHOULD BE ABOUT EQUAL TO THE DISTANCE TRAVELLED BY AIR MOVING FOR 5 TO 7 HOURS AT WIND SPEEDS PREVAILING DURING PERIODS OF PHOTOCHEMICAL ACTIVITY. FOR HEALTH RELATED PURPOSES, A MONITOR OUT OF THE MAJOR NO EMISSIONS AREA, BUT IN A POPULATED NEIGHBORHOOD IS DESIRABLE. PROSPECTIVE AREAS SHOULD ALWAYS BE OUTSIDE AREA OF MAJOR NO_x EMISSIONS

DETERMINE MOST FREQUENT WIND DIRECTION ASSOCIATED WITH IMPORTANT PHOTOCHEMICAL ACTIVITY

SELECT PROSPECTIVE MONITORING AREA UPWIND FOR MOST FREQUENT DIRECTION AND OUTSIDE AREA OF CITY INFLUENCE–SEE FIGURE 19

SELECT SPECIFIC SITE. AVOID VALLEYS; HILLTOP LOCATION DESIRABLE. AVOID INFLUENCE FROM NO_x SOURCES. MINIMUM SEPARATIONS FROM ROADWAYS:
ADT < 1000, 20 m
ADT = 1000 TO 10,000, 20–250 m
ADT > 10,000, > 250 m
INLET SHOULD BE WELL REMOVED FROM OBSTACLES AND AT A HEIGHT OF 3 TO 15 m

FIGURE 21 SCHEMATIC DIAGRAM OF PROCEDURE FOR SELECTING OXIDANT MONITORING SITES

monitoring would be to the southwest of St. Louis. The regional background monitor should be as far from any urban area as possible, preferably outside the areas of urban influence as defined in Figures 19 and 20.

The monitoring site should not be in a low-lying area, because such areas are much more likely to be subject to destructive processes at the surface during times of pronounced atmospheric stability. A location on top of a small hill will minimize the effects of the surface destructive processes, and hence will be desirable. Avoidance of NO sources is particularly important for this kind of site. The identification of those areas around a large point source of NO where NO_x interference is probable has been discussed already. Traffic sources of NO should not be nearby. Figure 21 provides minimum suggested separations between the monitor and roadways. It is important to separate the monitor from obstructions. If the monitor is located atop a small hill or knoll, it will minimize destructive effects of trees or other nearby obstacles. Even atop a hill the monitor should be no closer to any obstruction than about twice the height of the obstruction above the monitor. It is important when monitoring ozone to have the inlet away from vertical surfaces, because ozone is easily destroyed by contact with surfaces.

An inlet height of about 3 to 15 meters is desirable. Concentrations measured near the upper end of this range are probably more representative of background concentrations in the lower troposphere, but a compromise must be struck between the sampling of these more representative concentrations and the possible destruction of ozone during passage through a long inlet tube.

5.2.3.2. Neighborhood Scale Monitoring Sites

There are two monitoring alternatives in a neighborhood scale site. The desire may be to monitor the highest oxidant concentrations within the urban area or to characterize oxidant concentrations that are typical of the population exposure. In the latter case, as shown in Figure 21, prospective sites will be in reasonably homogeneous neighborhoods within the urbanized area. The neighborhoods considered should be away from the influence of major NO sources. In general, this would eliminate siting in heavily industrial neighborhoods, although there are conceivable instances when the characterization of ozone concentrations in such neighborhoods would be of interest. The specific site within a neighborhood should meet the criteria noted in Figure 21.

Figure 21 also shows how to select areas where the highest oxidant concentrations are to be found. It will not be possible to identify the point of maximum ozone concentration with absolute certainty, but it is possible to make qualitative estimates of the best places to locate monitoring sites. The best strategy is probably to recognize the difficulty in identifying a single site that will measure the area's highest concentrations and locate several stations in likely places. Once the decision has been made to locate a site near the highest concentrations in the area, it is then necessary to determine the most frequent wind speeds and directions for periods that are conducive to photochemical formation of oxidants. Existing monitoring data can be used to identify specific days when high ozone concentrations were observed and these days can be examined to determine the characteristic wind patterns. If there are no historical oxidant data, air temperature will provide a reasonable measure of the potential for photochemical production of ozone. Another possibility is to use wind data for the season and hours when ozone concentrations are apt to be the highest. Since high ozone concentrations are most likely to occur in the summer months or early fall, the monthly wind rose maps in the Climatic Atlas (National Oceanic and Atmospheric Administration, 1968) would tell the user the most frequent wind directions during the oxidant season. The monthly wind rose is not as good as historical oxidant data or a high temperature wind rose because it does not provide information concerning wind speed during oxidant episodes. Also, the monthly wind rose will include nighttime hours and days when ozone formation was low. The monthly wind rose should be used as a last resort.

Emissions inventories define the limits of the area within which most of the NO_x and NMHC emissions take place. Alternatively, the outer bounds of the urban areas defined on conventional topographic or street maps can be used, because the edges need not be defined very precisely. Photochemical formation of ozone takes place over a long period of time (hours) so that mixing will obscure the effects of any fine scale details in the emissions field.

The areas where maximum oxidant is most likely will be outside the region of major NO emissions, but within the radii of influence defined by OAQPS and shown in Figure 20. The oxidant maxima are apt to be found in the downwind direction so the area that must be considered is an angular segment of perhaps 45° that extends from the edge of the city to as far as 150 km from the city center. The area that has to be considered can be reduced further by recognizing that concentrations of precursors will continue to increase as the air passes over the source region. Once the air moves beyond the source region, dilution will reduce concentrations of the precursors and ozone formed from them. As long as ozone production is rapid enough to offset dilution, the concentration will continue to rise. By mid- to late-afternoon the ozone production will no longer be able to offset dilution and destruction processes. This suggests that one might determine where the pollutants from the morning rush hour are at mid-afternoon; that would be a likely location for high ozone concentrations. The air leaving the upwind (for photochemically favorable meteorological conditions) side of the city during the morning rush hour will accumulate more precursor pollutants during its history than the air which was on the downwind side of the city at the same time, hence the suggestion that the 5 to 7 hour travel distance recommended in Figure 21 be measured from the upwind side of the city.

Under light wind conditions, e.g. 10 km h^{-1}, such as might accompany high ozone concentrations, the distance would be about 50 to 70 km from the upwind edge of the city. For an ordinary, symmetric city with a diameter of 50 km, the promising monitoring areas are about 25 to 45 km from the center of the city. If air leaving the upwind side of the city during the morning rush hour is still within the emissions area during mid-afternoon, then it will still be under the influence of NO emissions which reduce observed ozone concentrations. In an extensive metropolitan area, the most likely locations for maximum ozone concentrations will be several kilometers beyond the downwind edge of the city. In very extensive metropolitan areas there may be relatively unpopulated "islands" within the widespread sea of NO emissions; such islands would be candidate areas for high ozone concentrations. However, choosing unpopulated islands or more rural areas beyond the fringes of the metropolitan area deemphasizes the importance of health effects. Some subjective decisions will have to be made about the importance of monitoring the maximum ozone concentrations wherever they may occur versus the monitoring of the maximum ozone concentrations to which appreciable portions of the population are exposed.

The minimum separations given in Figure 21 will reduce the effects of ozone destruction at the surface or by NO emissions. The monitor should be away from obstacles and the inlet should be away from vertical surfaces. An inlet height of 3 to 15 meters is suitable. In the case of oxidant monitoring, it is very important to avoid low lying areas. Monitoring on a slight rise or knoll has some advantage in helping to reduce ozone destruction by surrounding surfaces, especially during the late afternoon or evening hours. However, the importance of minimizing these destructive effects may have to be weighed against a desire to monitor conditions typical of those to which the population is exposed.

6. RATIONALE FOR SITE SELECTION CRITERIA

6.1. Background

The following three problem areas must be addressed during the siting process:

1. A simple method must be devised to identify the meteorological conditions that are conducive to photochemical activity.

2. A method must be devised to identify the regions where:

- concentrations are near their maximum and where concentrations are typical of the region of interest
- concentrations of reactants can be measured that are important in subsequent photochemical processes
- public exposure to a criteria pollutant will be significant.

3. The specific characteristics of a monitoring site that will minimize local, non-representative effects have to be determined.

This section describes the reasons for the recommendations given in the preceding section. It attempts to solve the problems listed above. Each of the three major problem areas are addressed separately.

6.2. Identification of Conditions Conducive to High Pollutant Concentrations

6.2.1. Conditions Conducive to Photochemical Activity

The essential ingredients for the photochemical formation of high concentrations of ozone are:

- an accumulation of precursor emissions
- sunshine
- relatively little ozone removal.

The last item, relatively weak removal of ozone, depends more on location than on meteorological factors and will be discussed later.

Ozone data provide the best means of identifying the meteorological conditions during past high ozone incidents, and hence the characteristic wind patterns that prevail during high ozone days. If there are no ozone data, another approach must be taken to identify meteorological conditions likely to accompany high ozone concentrations. A practical approach must use common meteorological data collected at airports and archived by the National Climatic Center in Asheville, North Carolina. Meyer et al. (1976) compared ozone concentrations observed during afternoons[1] with conditions that the air had been exposed to along its trajectory. The highest correlations were between ozone and air temperature during the last three hours before arriving at the observing site. They found correlation coefficients that ranged from 0.37 to 0.71. The overall correlation, for all six sites and all 372 trajectories, was 0.52. The temperature-ozone correlations found for urban sites were very similar to those found for rural sites.

Ludwig, Reiter, et al. (1977), using a method of analysis similar to that used by Meyer et al. (1976), obtained similar results. All their sites were rural[2]. The correlations between ozone and temperature were based on 30 cases for each site and ranged from 0.57 to 0.81. The temperatures used were the average of those observed during the last 12 hours of the trajectory. The correlation for the combined data was 0.54. Price (1976), using only cases when the ozone concentration exceeded 150 ppb, obtained a correlation of 0.27 between ozone concentration and temperature (at the same hour and location). Presumably the correlation would have been higher if the sample had included instances of lower ozone concentrations. No other variable seems to provide as good a description of ozone concentration as temperature.

---

[1] Stations used were Indianapolis, Indiana; Houston, Texas; Boston, Massachusetts; Poinette, Wisconsin; McConnelsville, Ohio; and Dubois, Pennsylvania. The data were from the months of July and August 1974.

[2] The stations used were McHenry, Maryland; Queeny, Missouri; Wooster, Ohio; and Yellowstone Lake, Wisconsin.

Figure 22 is a scattergram from Ludwig, Reiter, et al. (1977); joint occurrences of ozone concentration and average temperature are marked by the asterisks. Where there were more than one occurrence of the same combination of temperature and concentration, the number of occurrences are plotted. The scattergram shows that in only two instances (of 120) did the ozone concentration exceed the federal standard when the average temperature along the trajectory during the preceding 12 hours remained below 70°F. There were only 13 cases when the average temperature exceeded 75°F and ozone remained below the standard.

Seasonal variations in ozone concentration also provide an approach to the determination of meteorological conditions conducive to ozone formation. Ludwig, Simmon, et al. (1977) prepared analyses of ozone concentrations in the eastern United States like that shown in Figure 23 for every day of the year 1974. These analyses reveal those meteorological conditions that accompany high ozone concentrations at different locations in the eastern United States. The frequencies of ozone standard violations in different parts of the United States for each month of the year are given in Table 10. The table shows that high ozone concentrations are most frequent in the months of June, July and August. In some areas, more than two-thirds of the days experienced violations of the federal ozone standard during the summer months so the monthly wind roses for these locations should provide reasonable estimates of the wind direction associated with high ozone concentrations. The oxidant standard was violated at one or more locations in the Los Angeles Basin for every day of July and August, 1975 (California Air Resources Board, 1975). In the San Francisco Bay Area, about one-third of the days showed violations somewhere in the area and in the San Joaquin Valley, the figure was over 80%.

Table 11 (from Ludwig, Reiter, et al., 1977) provides another means for identifying winds that accompany high ozone concentrations. Light winds are frequent companions to high ozone concentrations. This is consistent with other work (e.g. Price, 1976; Meyer et al., 1976) that found high ozone concentration associated with weak pressure gradients and light winds. Table 11 shows that southerly winds are frequently associated with high ozone concentrations in several of the areas.

6.2.2. Conditions Conducive to High Concentrations from Smokestack Emissions

In general, atmospheric instability mixes pollutants emitted from elevated stacks to the ground before much dilution takes place and hence leads to high ground level concentrations; however, this type of atmospheric behavior is usually short lived and the resulting concentrations are short-term. Long-term average ground level concentrations arising from stack emissions are more likely to have the location of their maxima determined by those combinations of meteorological conditions that are most frequent. The neutral stability class (see for example Gifford, 1961) can occur at any hour of the day, unlike the stable and unstable categories. Therefore, the neutral class is the most commonly occurring stability. The most commonly occurring combination of wind speed and wind direction for the neutral stability category will often determine where the maximum long term average concentrations will occur at ground level.

6.3. Identification of General Areas Suitable for Monitoring

6.3.1. Nonmethane Hydrocarbons and Oxides of Nitrogen

6.3.1.1. General Considerations

Ludwig and Kealoha (1975) have shown that most of the concentration of an inert pollutant whose sources are near ground level come from sources within a few kilometers of the

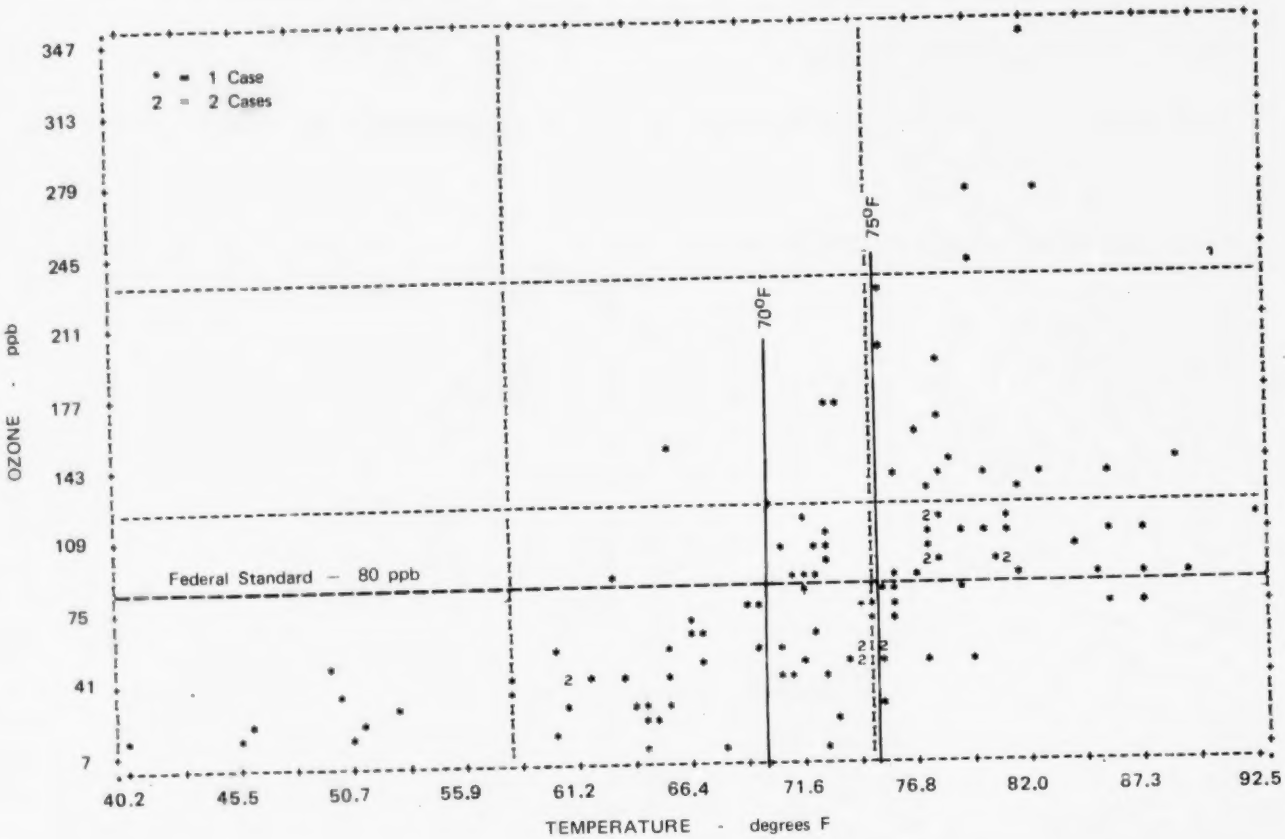
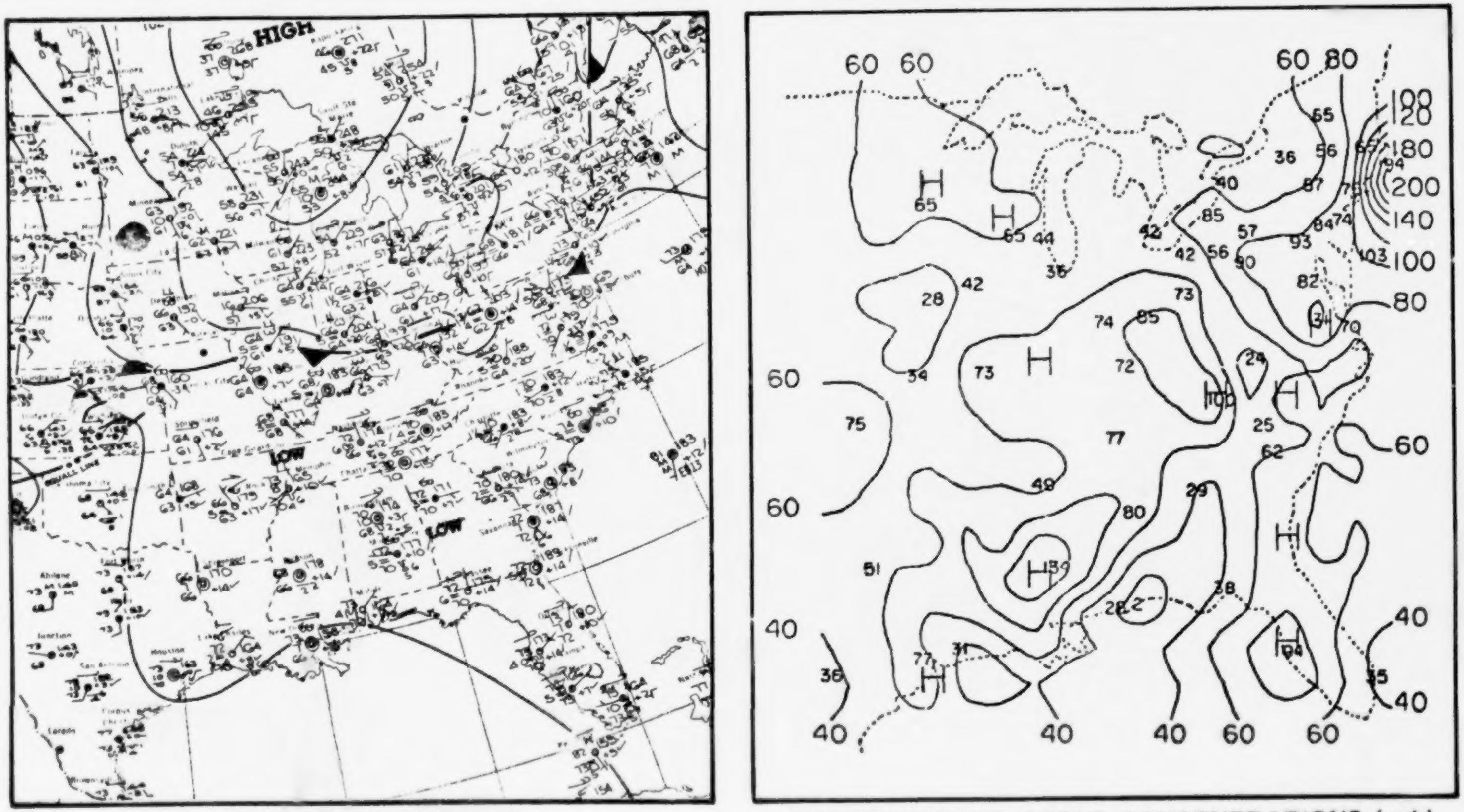


FIGURE 22 SCATTERGRAM OF PEAK HOUR OZONE CONCENTRATION VERSUS AIR TEMPERATURE ALONG THE TRAJECTORY FOR THE PRECEDING 12 HOURS


HIGH
LOW
LOW
60
80
100
120
140
180
200
40
H

1200 GMT WEATHER MAP

MAXIMUM-HOUR OZONE CONCENTRATIONS (ppb)

FIGURE 23 AN EXAMPLE OF A WEATHER MAP AND DISTRIBUTION OF PEAK HOUR OZONE (14 August 1974)

Table 10

MONTHLY FREQUENCY (1974) OF OXIDANT STANDARDS VIOLATIONS IN VARIOUS REGIONS OF THE EASTERN U.S.

	January	February	March	April	May	June	July	August	September	October	November	December
Florida Peninsula	0	0	5	3	8	10	9	3	1	2	0	0
Texas-Louisiana Gulf Coast	0	2	5	5	8	13	15	11	4	10	2	1
New England	2	0	0	6	10	18	9	18	13	1	0	0
Western Oklahoma, Kansas, Nebraska	0	0	3	8	22	20	22	20	12	15	1	0
SE of Lakes Erie & Ontario	0	0	0	0	2	2	20	21	2	0	0	0
Washington-Philadelphia Corridor	0	0	0	2	3	1	15	7	3	5	2	0
S or SW Shores of Lake Michigan	0	0	0	0	1	2	10	9	2	0	0	0
St. Louis and Ohio River Valley	0	0	0	0	3	3	22	13	5	0	2	0
Other Areas	0	2	1	5	0	2	6	6	5	5	0	2

Table 11

WINDS REPORTED ON MORNING WEATHER MAP IN AREAS WHERE PEAK-HOUR OZONE EXCEEDED 80 ppb

(No. of days from June through August)

Region	Surface Winds				
	Calm	≥ 2 m/s			
		N to E	E to S	S to W	W to N
Florida Peninsula	11	5	4	2	0
Texas-Louisiana Gulf Coast	17	10	0	7	1
New York-New England	3	4	7	26	2
Western Oklahoma, Kansas, Nebraska	1	7	13	36	11
SE of Lakes Erie and Ontario	20	1	10	6	1
Washington-Philadelphia Corridor	9	5	7	7	4
S or SW shore of Lake Michigan	7	0	5	6	1
Ohio River Valley & Surroundings	21	2	1	7	0

monitor. This fact underlies the suggestion that the general areas for reactant oriented monitoring be chosen on the basis of emissions inventories. Concentrations in areas of typical emissions will tend to be characteristic of the region as a whole. Figure 24b shows the distribution of average NO_x concentrations in the Los Angeles Basin for the year 1975; Figure 24d shows the distribution of the 1 percentile values of daily peak hour NO_x concentrations. This latter representation shows the concentrations which were exceeded on only 3-4 days during the year. In both instances there is an area of high concentrations that corresponds roughly to the most populated part of the basin. The high values observed at the Lennox site in the southwest part of the basin may be the result of that site's proximity to several major roadways and the Los Angeles International Airport (see for example Perkins, 1973). The figures support the assumption that the concentrations are distributed roughly in accordance with the emissions distribution.

The displacements of concentration relative to emissions can be related to transport by winds. Figure 25 shows typical afternoon and early morning air flow patterns in the Los Angeles Basin (Los Angeles Air Pollution Control District, 1974). The NO_x patterns are distended to the east and to the northwest, more or less along the streamlines shown in Figure 25a. The air flow patterns shown in the figure are much the same in summer and winter, but with differences in strength. In the summer, the afternoon wind speeds typically reach 7 or 8 $m\ s^{-1}$; in the winter about 5 $m\ s^{-1}$. The nighttime pattern shown in Figure 25b has stronger winds in winter, 2 to 5 $m\ s^{-1}$, than in the summer, 2 to 3 $m\ s^{-1}$. When monitoring products, consideration must be given to the delay that takes place between the emission of the reactants and the formation of the products. This delay will separate the location of the maximum product concentration from the location of the maximum reactant emissions. In the case of ozone, the separation may be quite large. In the case of NO_2, the time that it takes to form from the originally emitted NO can be quite short if local ozone concentrations are high or longer if ozone concentrations are low.

6.3.1.2. Location of Areas of High Concentrations

It is apparent from the above discussion that there are three different conditions that lead to high NO_2 concentrations. The first of these causes high NO_2 concentrations in the vicinity of an area of strong NO emissions when ozone concentrations are high and winds are nearly stagnant. The second condition occurs when ozone concentrations are high (so that rapid transformation occurs from NO to NO_2 before much dilution occurs) and the winds are appreciable so that the NO_2 maximum is displaced downwind slightly from the NO emissions. The third condition leading to high NO_2 concentrations would be stagnation with little ozone present. The emitted NO could accumulate for long periods of time and gradually undergo the oxidation to NO_2. In this case, the NO_2 maximum would be found near the area of major emissions.

Under all three conditions, the separation between maximum concentration and maximum emission will be small. When the air is nearly stagnant the products cannot travel far from the emissions regardless of the speed of the reaction. When large amounts of ozone are present, the reactions proceed quickly so that NO_2 is formed before the air has had time to move very far from the sources. Figure 24a illustrates this effect. The distribution of average NO_2 concentrations is shown for the year 1975 in the Los Angeles Basin. It is evident that the maximum average NO_2 concentrations tend be displaced from the center of the city in the direction of the afternoon streamlines. This suggests that the location of average daily maximum NO_2 concentrations is usually displaced somewhat from the major source areas. However, Figure 24c shows the distribution of the one percentile daily maximum concentrations and they are nearly centered on the downtown Los Angeles area. This suggests that stagnation or the rapid transformation of NO to NO_2 are quite important in producing very high concentrations of NO_2, but less so in determining the location of average concentrations.

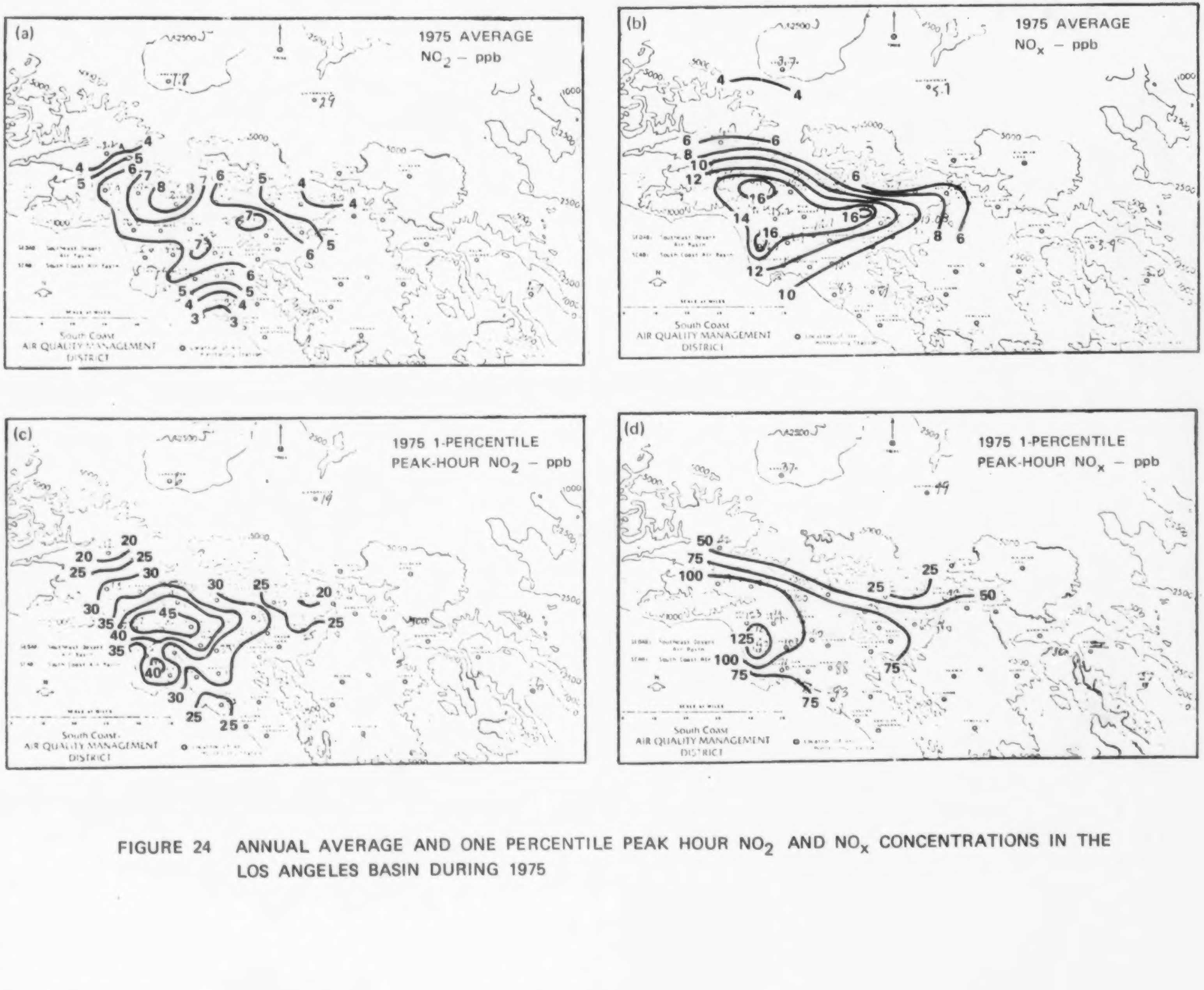

(a)
1975 AVERAGE
NO_2 – ppb
(b)
1975 AVERAGE
NO_x – ppb
(c)
1975 1-PERCENTILE
PEAK-HOUR NO_2 – ppb
(d)
1975 1-PERCENTILE
PEAK-HOUR NO_x – ppb
South Coast
AIR QUALITY MANAGEMENT
DISTRICT

FIGURE 24 ANNUAL AVERAGE AND ONE PERCENTILE PEAK HOUR NO_2 AND NO_x CONCENTRATIONS IN THE LOS ANGELES BASIN DURING 1975

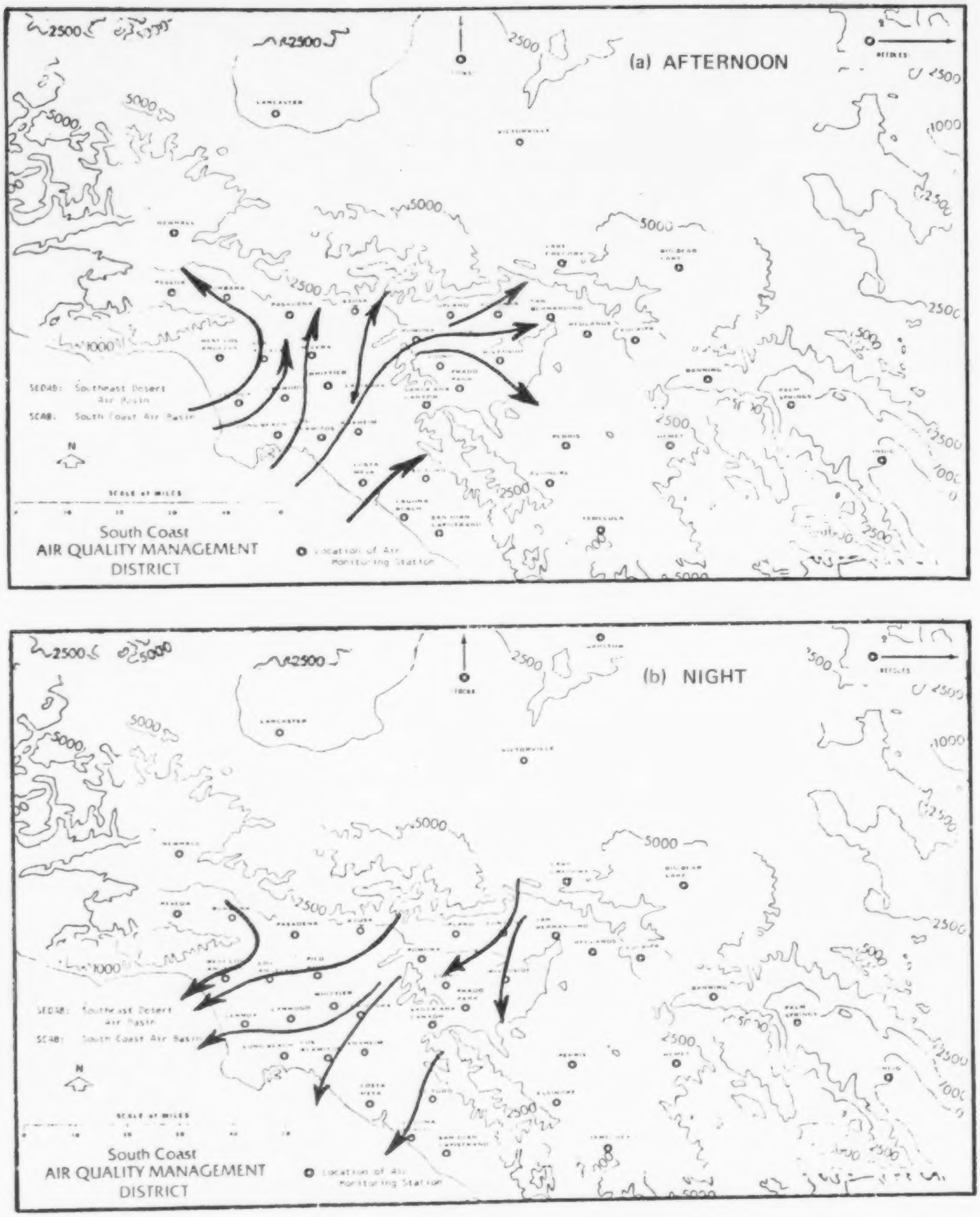

(a) AFTERNOON
(b) NIGHT
SEDAB: Southeast Desert Air Basin
SCAB: South Coast Air Basin
N
SCALE of MILES
South Coast AIR QUALITY MANAGEMENT DISTRICT
Location of Air Monitoring Station
2500
5000
1000

FIGURE 25 TYPICAL AIR FLOW PATTERNS IN THE LOS ANGELES BASIN

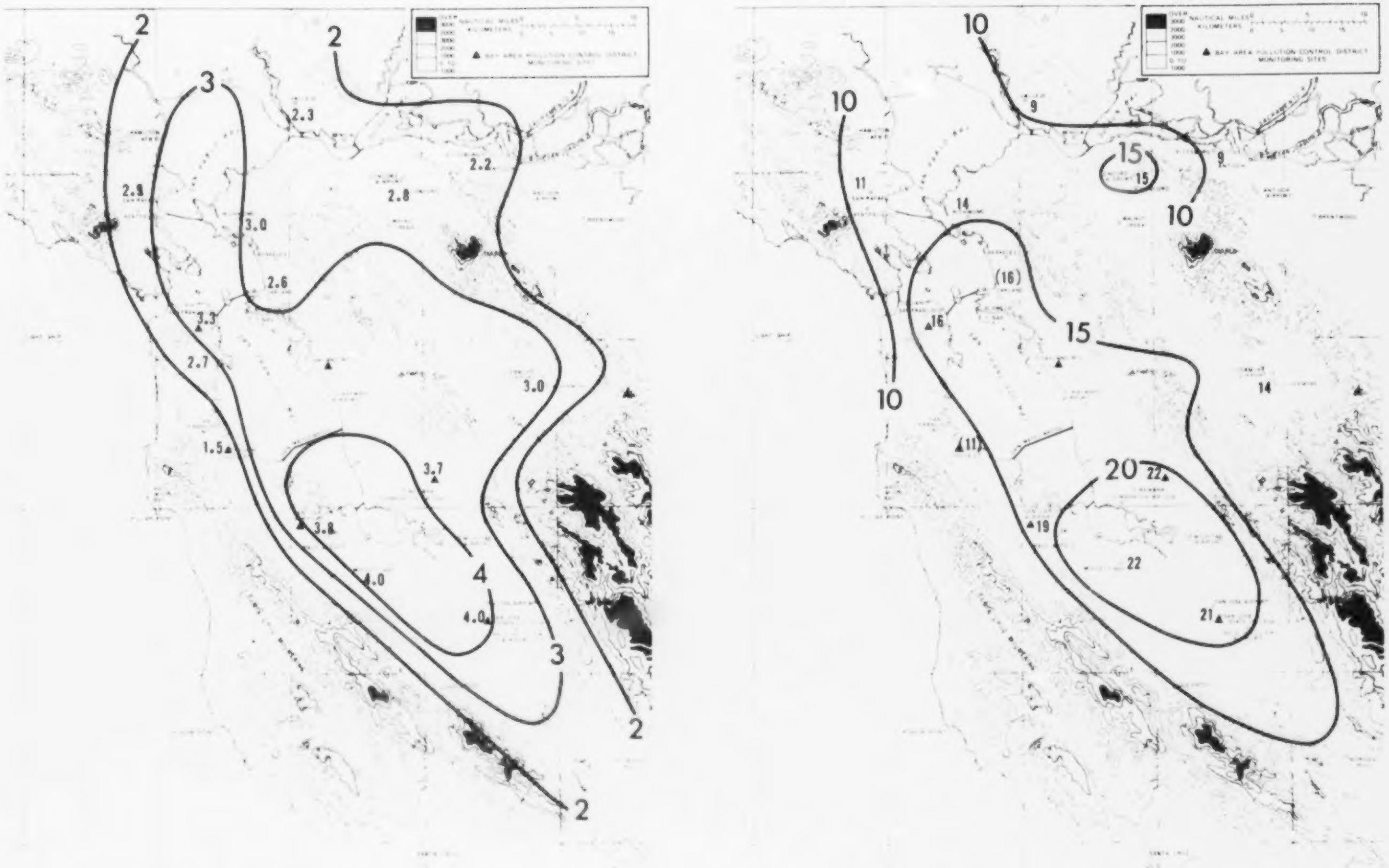
There is evidence of similar behavior in the San Francisco Bay area, although the density of NO_2 and NO_x data is not entirely adequate to document the effect. Figure 26 shows the 1975 average NO_2 concentrations and the 1975 one percentile peak hour NO_2 values. The highest concentrations occur in the populated areas around the edge of the Bay. The fact that the San Francisco concentrations are somewhat less and the San Jose concentrations are somewhat more than in the other populated areas around the Bay is probably a reflection of the differences in wind speeds, or ventilation, at these sites. San Francisco is subject to strong winds blowing through the Golden Gate while San Jose tends to have lighter winds than some of the other locations. Furthermore, as the typical flow patterns in Figure 27 indicate, pollution emitted elsewhere in the Bay area is transported to San Jose and provides an elevated background concentration to which local contributions are added. Differences between the average NO_2 concentrations for 1975 and the one percentile peak hour concentration values are not as evident as they are in the Los Angeles example. The Bay Area average concentrations and high percentile concentrations both are confined to the high emissions areas, with some distortion of the patterns along the typical streamlines.

Figure 28 shows the annual average NO_2 concentrations in southwest Ohio. The prevailing wind in this area is from the southwest (National Oceanic and Atmospheric Administration, 1968). The wind effects are evident in the figure; the concentrations increase rapidly as the city of Dayton is approached from the southwest and the patterns are distended to the northeast, downwind of the city. The pattern supports the observation that maximum long-term average NO_2 concentrations tend to be displaced in the downwind direction from areas of maximum emissions. Probably not all of the distortion in the pattern in Figure 28 is due to the wind; at least part may be the result of emissions in the vicinity of Wright-Patterson Air Force Base.

The distributions of 24-hour average NO_2 concentrations in southwestern Ohio were analyzed for 12 different days in 1974. In general, when the concentrations were relatively low, the patterns tended to be elongated in the direction of the wind. Of the days examined, the highest concentrations occurred on October 2, shown in Figure 29. The weather map and the ozone distribution for this day in the eastern United States are shown in Figure 30. The high pressure area to the west of Ohio moved eastward over Ohio on the following day. The near stagnation conditions associated with the high pressure area allowed NO_x emissions to accumulate and caused the widespread high NO_2 concentrations shown in Figure 29.

Up to this point the discussion has focused on the distribution of NO and NO_2 in space. There are other approaches to the interpretation of the data. A volume of air can be followed and the changes in concentration of various pollutants with time within that volume can be related to the emissions entering the volume. This approach has been applied in the San Francisco Bay Area. Figure 31 shows 20 of the 31 trajectories, based on surface winds, that were used for the analyses. The numbers at the end of the trajectories indicate the time of arrival at that point. The points along the trajectories show the location at one hour intervals. Ludwig and Kealoha (1974) describe the methods used in developing the analyses. Concentrations of oxidant and NO_2 along the trajectory were determined from isopleth analyses of the hourly values observed at the various monitoring locations in the area. The trajectories end at the time of maximum concentration at their terminous. In only one of the 31 trajectories studied did the maximum NO_2 and oxidant concentrations occur at the same time. In the remaining cases the oxidant concentration reached its peak 1 to 6 hours after the NO_2 concentration. The typical time lag was about 2 to 3 hours showing that the NO_2 maxima are upwind of the oxidant maxima.

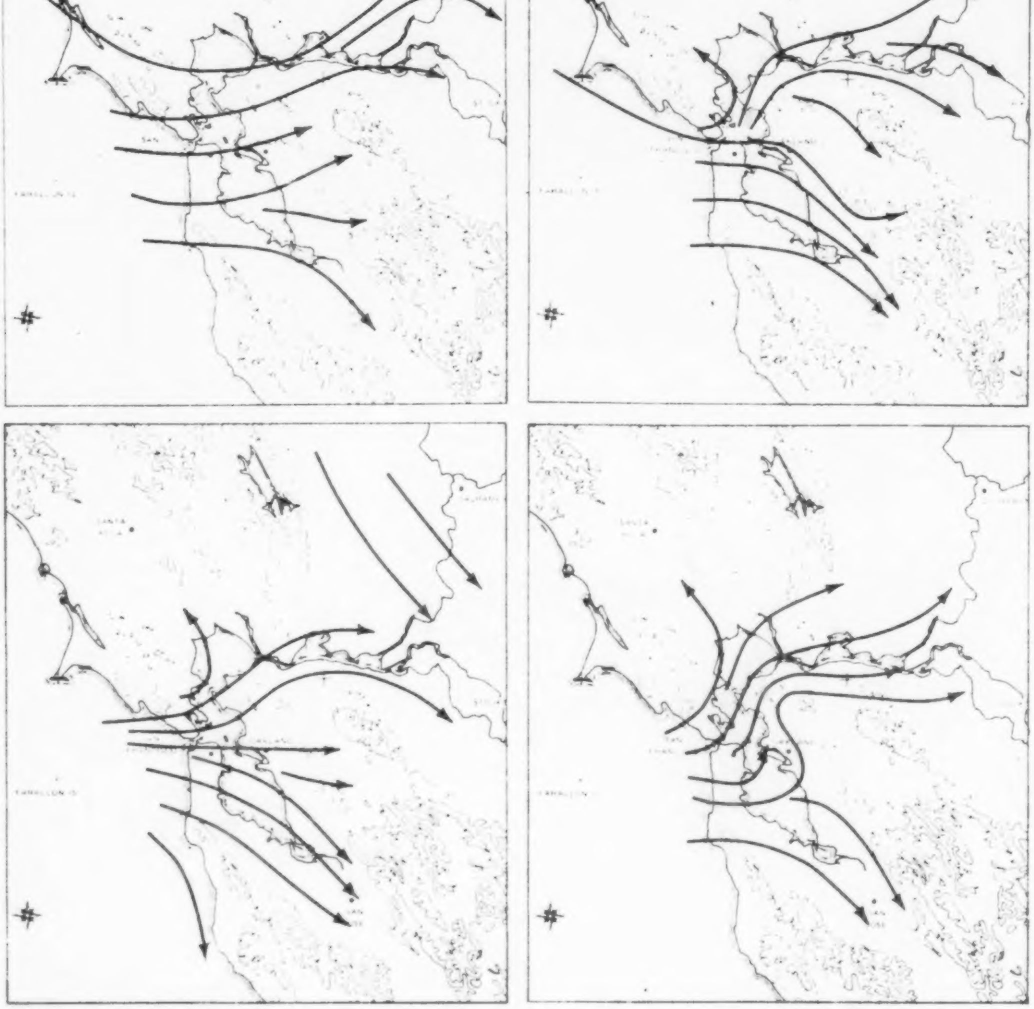
The trajectory analyses also showed that the changes in NO_2 concentrations generally lagged behind changes in NO_x emission rates by periods of about 2 hours or less. Figures 32 and 33 provide two examples of this behavior. The figures show the changes in concentration of NO_2 and ozone near ground level as the air moved along the path shown in the upper half of the figure. The changes in the emissions of NO and hydrocarbons are also shown. The units of the emissions are meters per minute. These seemingly anomolous units for emissions are


NAUTICAL MILES
KILOMETERS
▲ BAY AREA POLLUTION CONTROL DISTRICT MONITORING SITES
2
3
4
2.3
2.2
2.8
2.9
3.0
2.6
3.3
2.7
1.5
3.7
3.8
4.0
4.0
3.0
10
15
20
9
11
14
(16)
16
(11)
19
22
22
21
14
15

(a) 1975 AVERAGE NO_2(pphm)

(b) 1975 1-PERCENTILE PEAK-HOUR NO_2(pphm)

FIGURE 26 ANNUAL AVERAGE AND ONE PERCENTILE PEAK HOUR NO_2 CONCENTRATIONS IN THE SAN FRANCISCO BAY AREA FOR 1975



SOURCE: Smalley 1957

FIGURE 27 MOST COMMON DAYTIME AIRFLOW PATTERNS IN THE SAN FRANCISCO BAY AREA

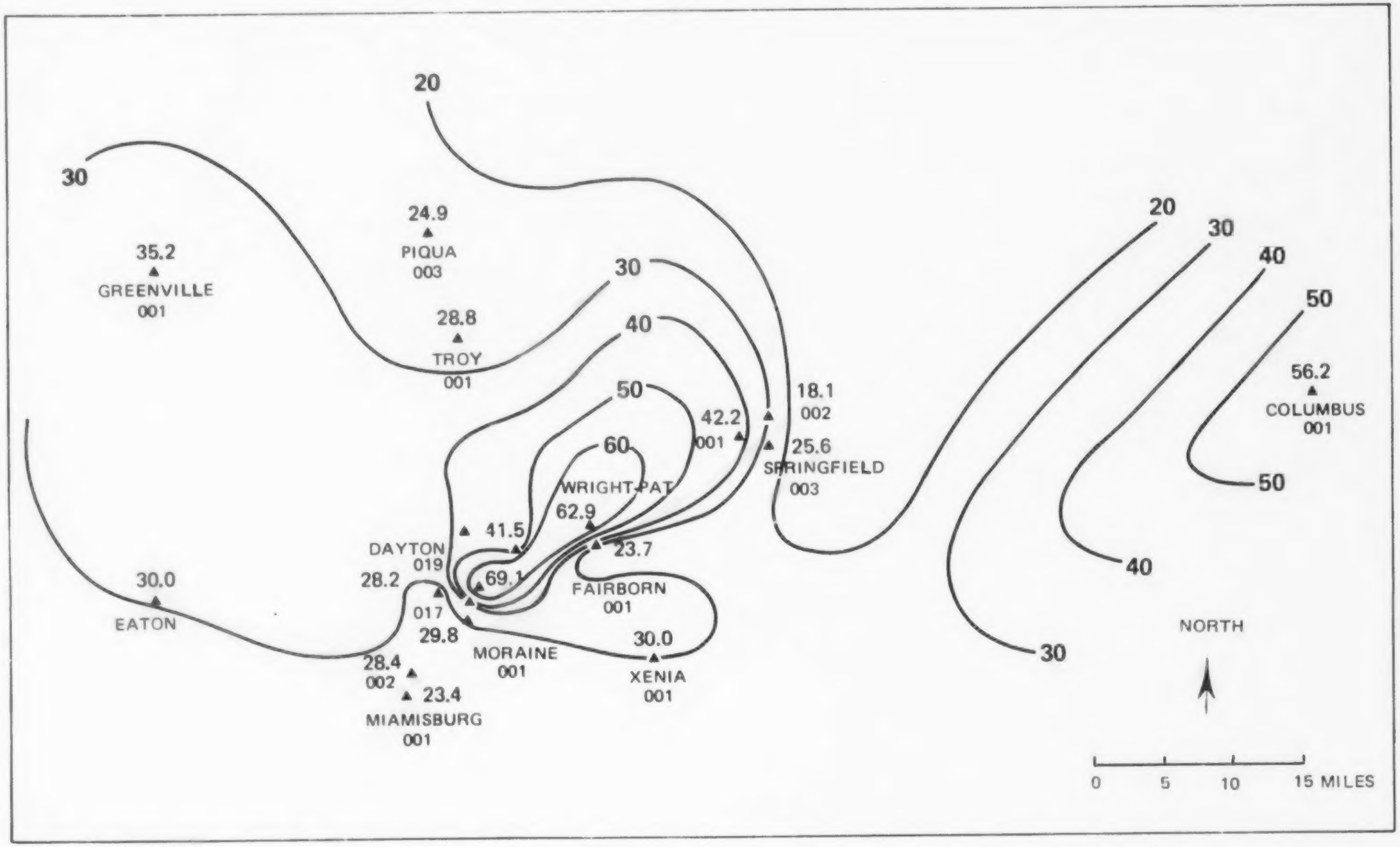

20
30
35.2
GREENVILLE
001
24.9
PIQUA
003
28.8
TROY
001
30
40
50
60
WRIGHT-PAT
62.9
42.2
001
18.1
002
25.6
SPRINGFIELD
003
41.5
DAYTON
019
69.1
23.7
FAIRBORN
001
30.0
EATON
28.2
017
29.8
MORAINE
001
30.0
XENIA
001
28.4
002
23.4
MIAMISBURG
001
20
30
40
50
56.2
COLUMBUS
001
50
40
30
NORTH
0
5
10
15 MILES

FIGURE 28 ANNUAL AVERAGE NO_2 CONCENTRATION (ppb) IN SOUTHWESTERN OHIO

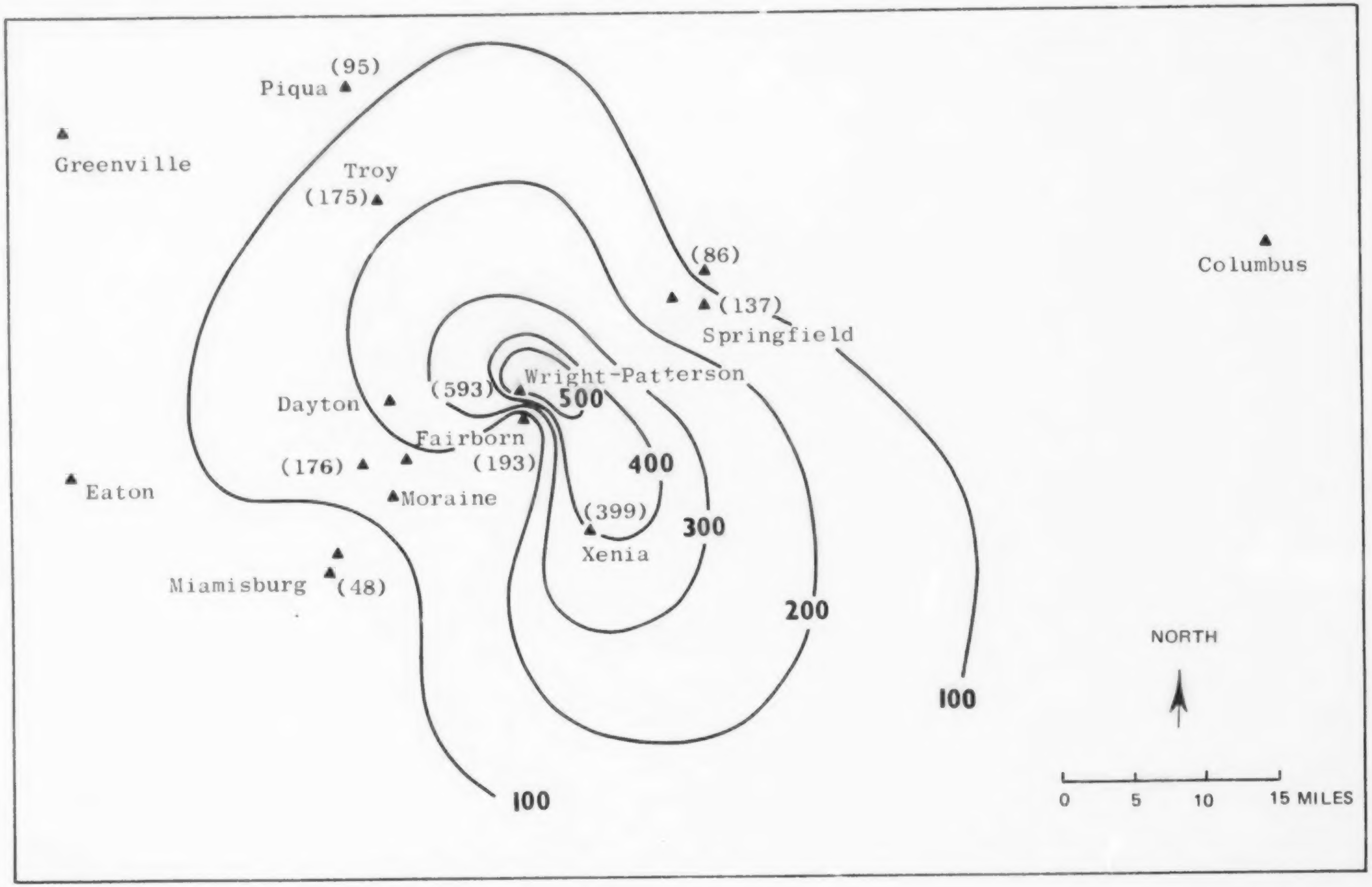
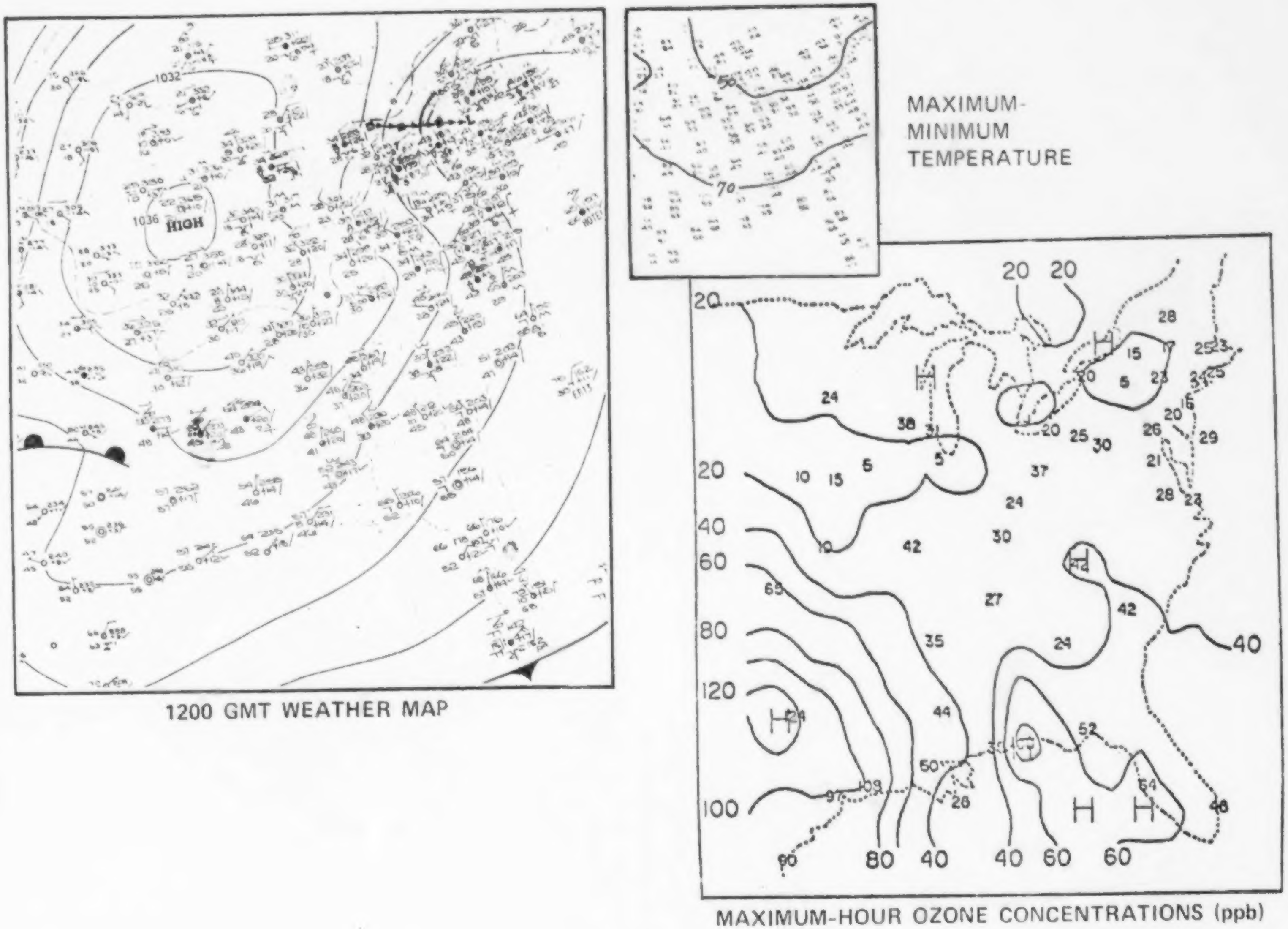

(95)
Piqua
Greenville
Troy
(175)
(86)
(137)
Springfield
Columbus
Wright-Patterson
(593)
500
Dayton
Fairborn
(176)
(193)
400
Eaton
Moraine
(399)
300
Xenia
Miamisburg
(48)
200
NORTH
100
100
0
5
10
15 MILES

FIGURE 29 24-HOUR AVERAGE NO_2 CONCENTRATION (ppb) IN SOUTHWESTERN OHIO, OCTOBER 2, 1974


1032
1036
HIGH
50
70
20
40
60
80
120
100
90
H
40
60

1200 GMT WEATHER MAP

MAXIMUM-
MINIMUM
TEMPERATURE

MAXIMUM-HOUR OZONE CONCENTRATIONS (ppb)

FIGURE 30 WEATHER MAP AND OZONE DISTRIBUTION IN THE EASTERN UNITED STATES, OCTOBER 2, 1974

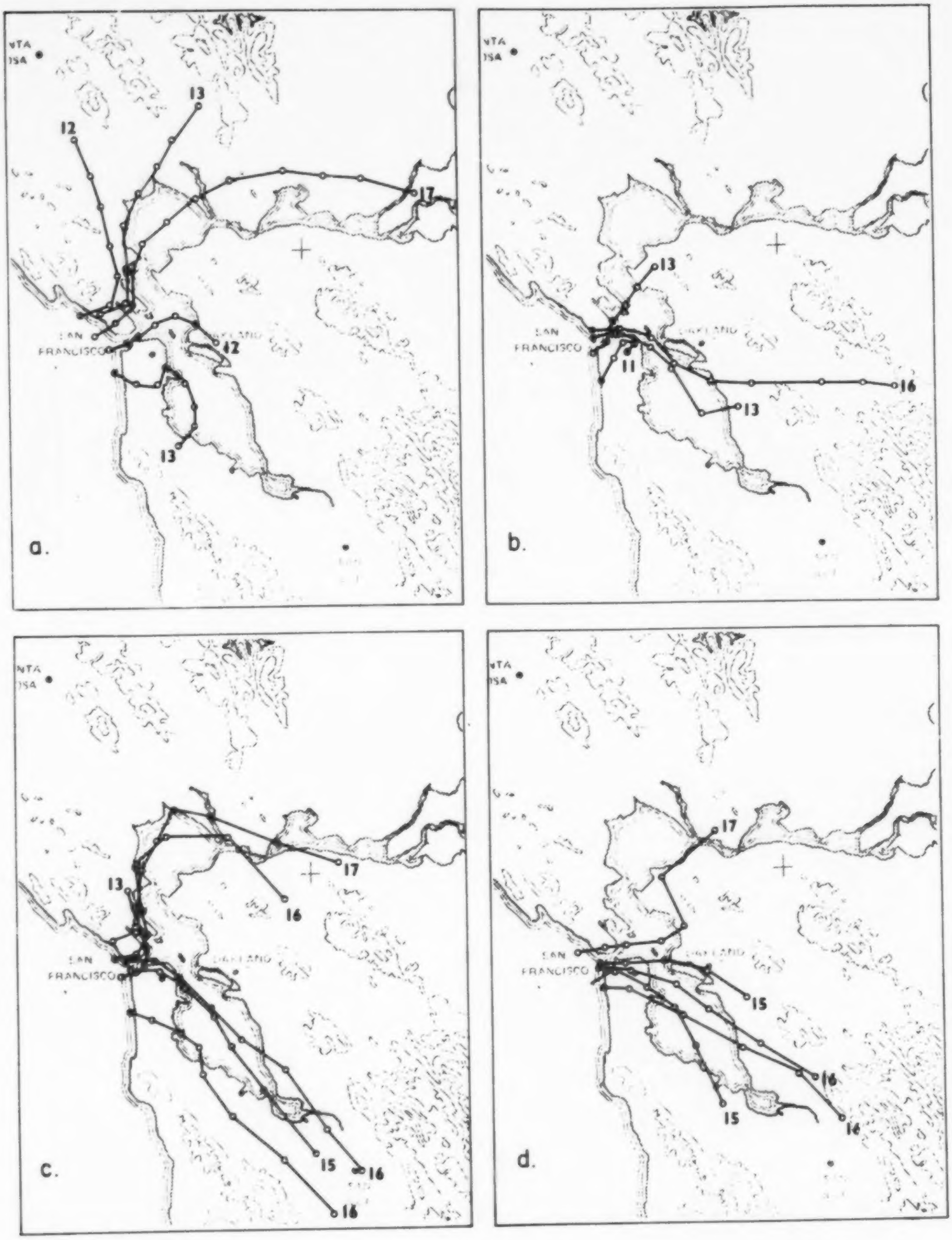

a.
13
12
17
SAN FRANCISCO
12
13
b.
13
SAN FRANCISCO
OAKLAND
11
16
13
c.
13
17
16
SAN FRANCISCO
15
16
16
d.
17
SAN FRANCISCO
15
16
15
16

FIGURE 31 SOME AIR TRAJECTORIES IN THE SAN FRANCISCO BAY AREA, JULY 2, 1970

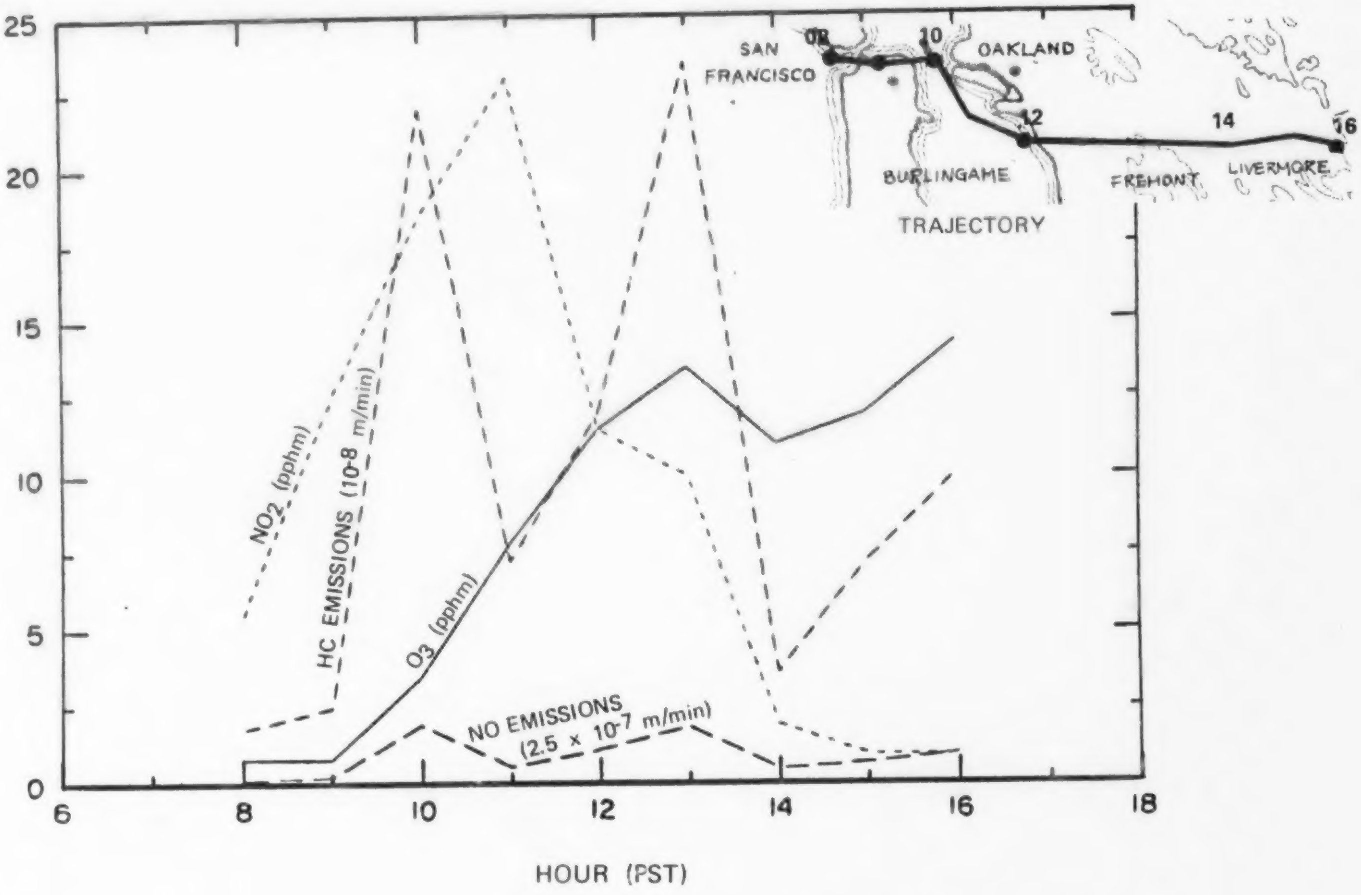


FIGURE 32 VARIATIONS OF NO AND NMHC EMISSIONS, AND NO_2 AND O_3 CONCENTRATIONS ALONG AN AIR TRAJECTORY TERMINATING IN LIVERMORE, CALIFORNIA ON JULY 2, 1970 (Units given in parentheses)

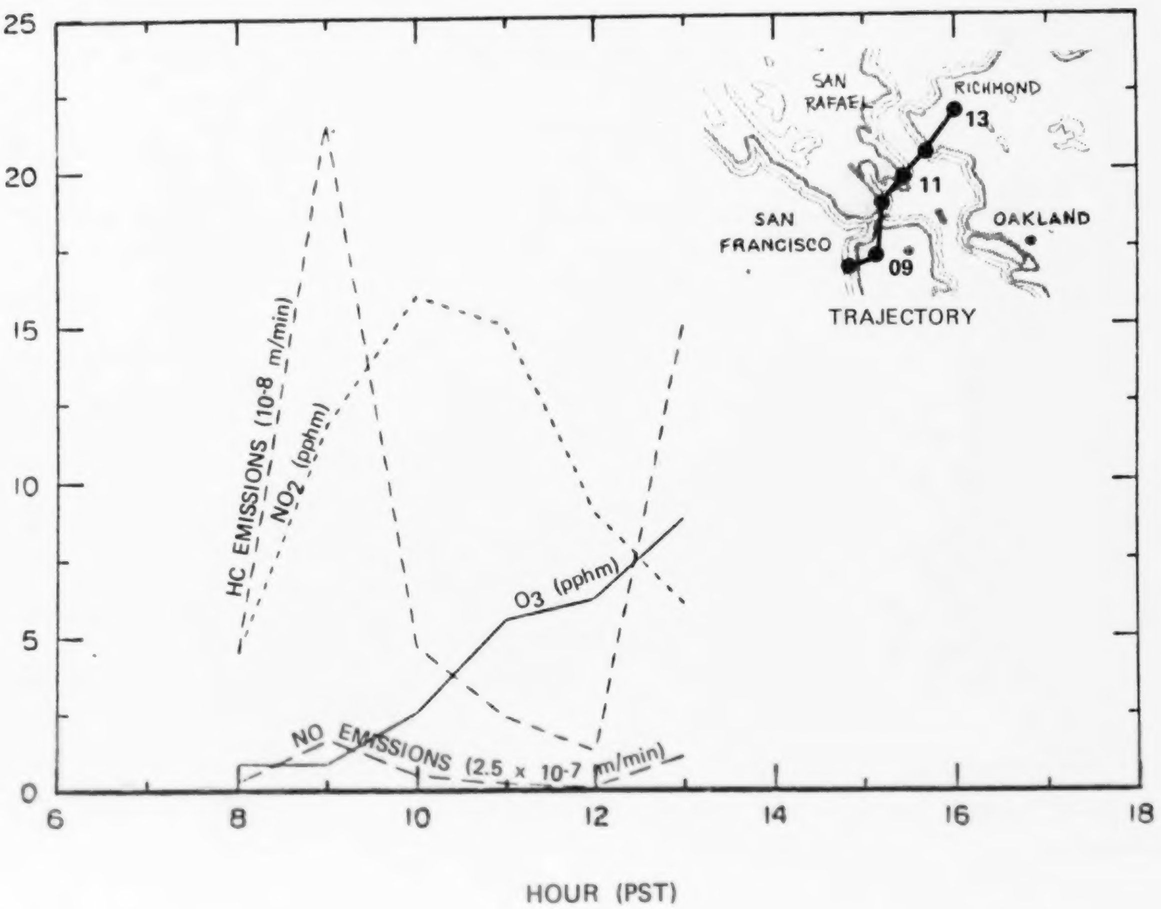


FIGURE 33 VARIATIONS OF NO AND NMHC EMISSIONS, AND NO_2 AND O_3 CONCENTRATIONS ALONG AN AIR TRAJECTORY PASSING THROUGH RICHMOND, CALIFORNIA ON JULY 2, 1970 (Units given in parentheses)

convenient for some modeling purposes. They can be interpreted as follows--if the emissions for one minute are introduced into the atmosphere at the surface without mixing, their depth would be that shown in the graph. Remembering that one g-mole occupies about 23 liters, the units can be interpreted in terms of g-mol m^{-2} min^{-1}--one mole m^{-2} min^{-1} equals about 23000 μm min^{-1}.

The above results suggest that during the day, NO_2 maxima are found downwind of major emissions sources at distances typically travelled by the air in one or two hours. Since the trajectories cover only daytime conditions with significant ozone buildup, the results are not to be generalized too much. The results do suggest that even under conditions that are favorable for the conversion of NO emissions to NO_2 concentrations, the conversion can require a few hours, which can translate into important spatial separations.

6.3.2. Oxidants.

6.3.2.1. General Considerations

It was stated earlier that maximum oxidant concentrations should be found about 5 to 7 hours travel time downwind (for conditions most conducive to oxidant formation) of the upwind edge of the metropolitan area. If the region identified in this way is within the area of major emissions, then the likely places for high ozone concentration will be just beyond the downwind edge of the major emissions area. The assumptions underlying the suggestion are as follows:

- maximum oxidant concentrations are most likely to accompany large accumulations of precursor emissions.
- Large accumulations of precursor emissions are most likely in air that travels across the entire emitting region, especially during the morning rush hour.
- Maximum oxidant concentrations are reached in the early to middle afternoon, after the morning rush hour emissions have been traveling 5 to 7 hours.
- Emissions of NO within the metropolitan area will destroy ozone near ground level and keep the concentrations below their maxima.

The recommendations for selecting areas of probable oxidant maxima are applicable to relatively large urban areas. For small areas, lateral mixing of clean air into the urban "plume" is apt to reduce both precursor and oxidant concentrations so that maximum oxidant concentrations will occur closer to the city than predicted. In large sprawling metropolitan areas there may be "islands" of low NO emissions; these islands may then be the locations of maximum oxidant concentration, rather than the downwind edge of the metropolitan area.

The following sections present evidence to support the recommendations. Examples of ozone maxima in several geographical areas are presented. Finally, evidence of ozone destruction by urban NO emissions is given.

6.3.2.2. The Transport of Ozone and the Location of Concentration Maxima

Figure 34 shows the buildup of ozone and NO_2 concentrations in a parcel of air that was over San Francisco during the morning rush hour. The figure shows very high hydrocarbon and NO emissions between 6 and 8 A.M. (PST) and lower emissions during the rest of the trajectory. The NO_2 concentrations rose to their maximum by about 1100. Oxidant levels remained quite low until about that time and then they rose to their peak concentrations at around 1400. Two more examples are given in Figures 35 and 36. In the first of these, the emissions were relatively high between 0600 and 0800 A.M. and then fell as in the preceding example. However, they rose again and remained high, rising sharply during the last half hour of the trajectory. The increased emissions near the end of the trajectory tended to truncate the increasing ozone concentrations. In the example shown in Figure 36, emissions were relatively high throughout, rising to a peak at the next-to-last hour (1400) and then falling. Oxidant concentrations continued to rise from early morning through the early to middle afternoon. A rise

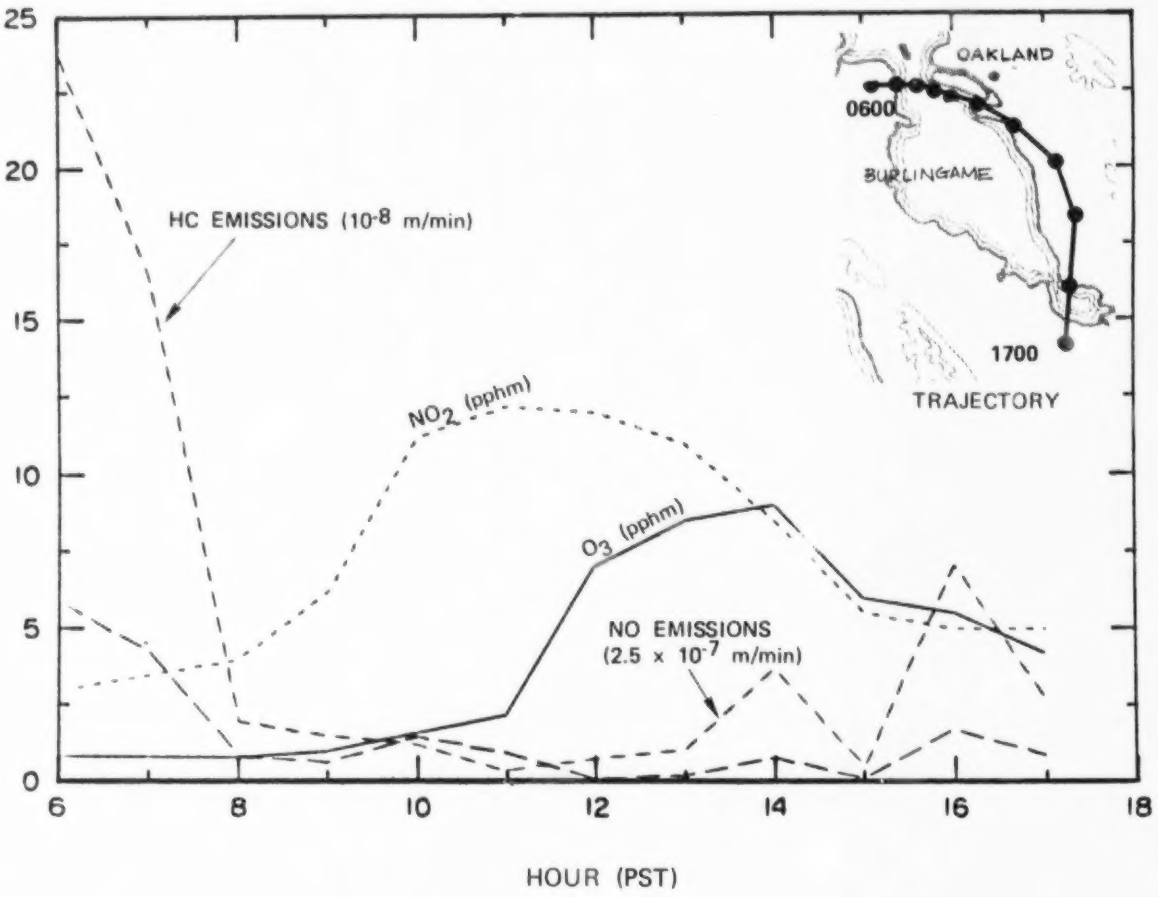


FIGURE 34 VARIATIONS OF NO AND NMHC EMISSIONS' AND NO_2 AND O_3 CONCENTRATIONS ALONG THE TRAJECTORY SHOWN, JULY 26, 1973 (Units given in parentheses)

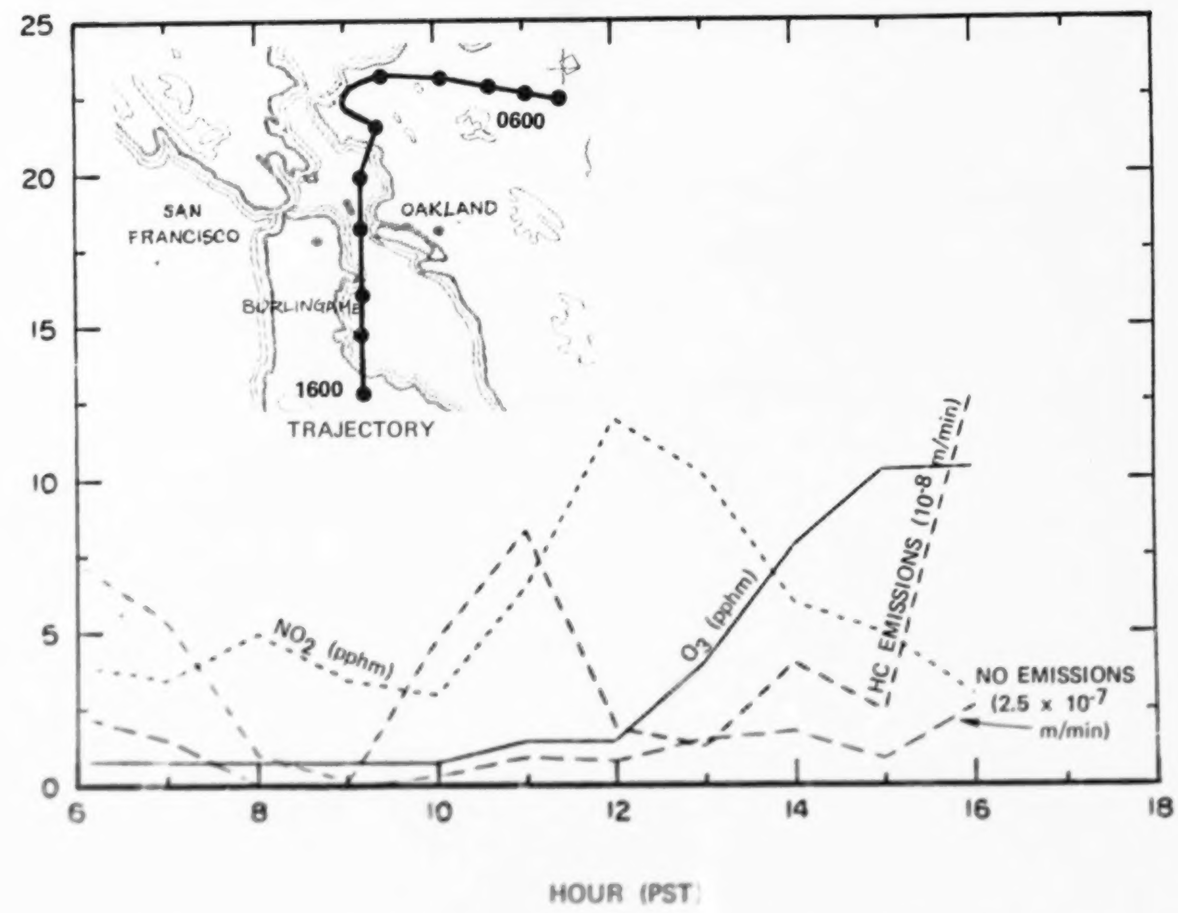


FIGURE 35 VARIATIONS OF NO AND NMHC EMISSIONS AND NO_2 AND O_3 CONCENTRATIONS ALONG THE TRAJECTORY SHOWN, SEPTEMBER 27, 1973 (Units given in parentheses)

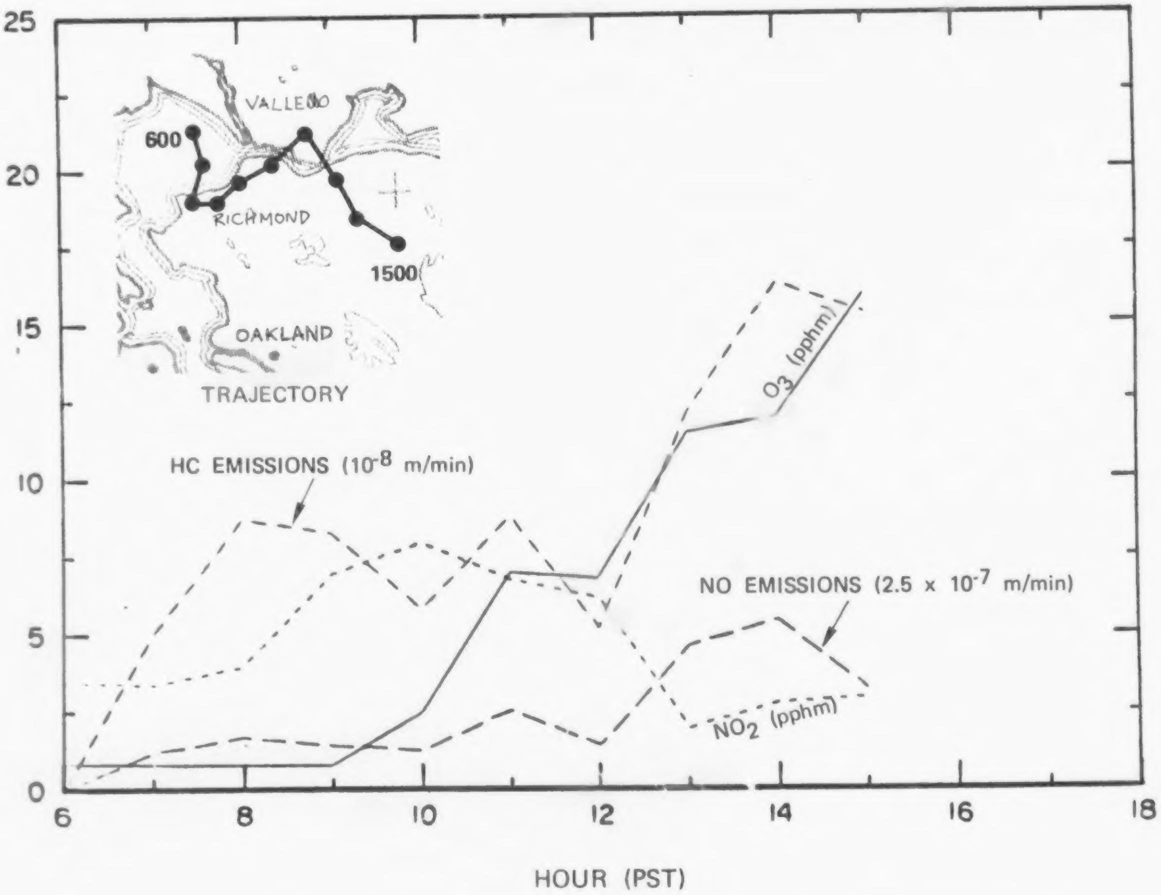


FIGURE 36 VARIATIONS OF NO AND NMHC EMISSIONS AND NO_2 AND O_3 CONCENTRATIONS ALONG THE TRAJECTORY SHOWN, JULY 26, 1973 (Units given in parentheses)

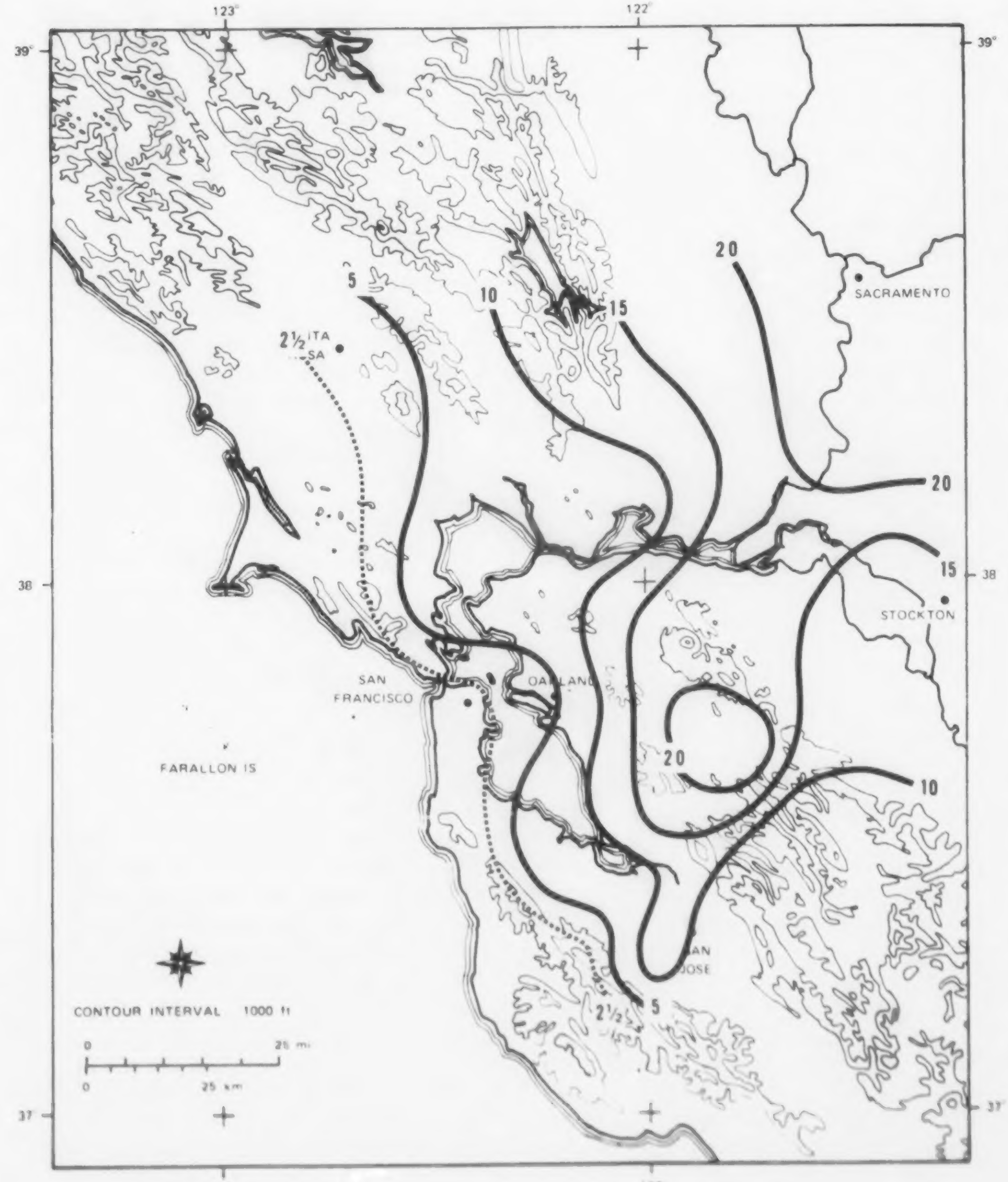
in oxidant concentration occurred when the major precursor emissions were confined mostly to the early part of the trajectory (Figure 34) and also for cases when precursor emissions were strong throughout the course of the air movement (Figures 35 and 36).

The trajectory analyses confirm that ozone concentrations tend to increase with time until early- to mid-afternoon and that the highest concentrations are likely to be found 5 to 7 hours downwind of the major emissions centers; the time interval represents the time between the morning rush hour emissions and early afternoon. The NO emissions within the city tend to retard the buildup of ozone so that in very large regions, such as the San Francisco Bay Area or the Los Angeles Basin, we would expect to find the ozone maxima just beyond the areas of major NO emissions. Figure 37 shows the frequency of oxidant standards violations in the Bay Area. It is clear from this figure that the most frequent violations occur at the southern and eastern edges of the metropolitan area, as expected. To the northeast, the maximum frequency of violations occurs well beyond the city, towards Sacramento. This may reflect the generally higher wind speeds through the Delta area and into the Central Valley. These higher wind speeds will carry the precursors beyond the urban area before maximum formation of oxidants occurs.

Figure 38 shows the 1-percentile peak-hour oxidant readings for the Los Angeles area for 1975. The maxima are along the downwind edge of the city. There is also a ridge of high values extending to the east-southeast, probably reflecting the general transport of air from the Los Angeles Basin out into the desert regions. Figure 38 shows that the maximum ozone concentrations may occur near the downwind edge of a large metropolitan area, but important effects from that metropolitan area may extend well beyond the area of maximum concentration. This is observed in other areas as well as Los Angeles. The effects of the New York Metropolitan area on surrounding areas have been studied by Cleveland et al. (1975). They compared maximum daily ozone concentrations measured during the summer of 1974 at numerous New England monitoring sites with the wind directions during the same day and showed that the highest ozone concentrations occurred with wind directions from New York. Even Boston, nearly 300 km from New York, showed the effect. They only considered days with well defined wind directions and temperatures above 70°F at Hartford, Connecticut.

Ludwig and Shelar (1977) also examined the distribution of ozone concentrations in the New England area. Figure 39, shows the observed maximum hour average ozone concentrations at seven sites during the period from July 15 to August 31, 1975. The sites are arranged from bottom to top in order of increasing distance from New York City--ranging from Bridgeport at about 80 km to Boston at about 300 km. An asterisk represents one observation; a numeral represents multiple cases. Weekend values are plotted above the weekday values. The tendency toward decreasing ozone concentrations with increasing distance from New York is apparent. The Spearman rank correlation (Langley, 1970) between the upper decile ozone concentrations and the distance from New York shows a negative correlation, significant at the 3 percent level. Upper decile values were chosen because the effect should be greatest for the high ozone cases.

Ludwig and Shelar (1977) examined the data from the Northeast Oxidant Study (Siple et al., 1976; Spicer, et al., 1976; Washington State University, 1976; Wolff et al., 1975) and found evidence of ozone "plumes" from urban areas. Figure 40 shows the distribution ozone concentrations on August 10, 1975. This was a day of weak pressure gradients with light winds in the southern New England area. The observed pressure gradients should have caused general surface airflow from west or west-southwest. The winds at 850 mb (approximately 1500 m altitude) shifted during the day from west-northwest to west-southwest. Thus, the pollutants from the urban areas should have traveled east or east-northeast during the day. As Figure 40 shows, concentrations exceeded 150 ppb along the south coast of Connecticut. Although the lack of data from eastern Long Island prevents confirmation, it appears that the highest concentration probably occurred over Long Island or Long Island Sound. The hours during which the highest values were observed along the Connecticut coast were in the early afternoon, around 1300 or 1400 EST. Figure 40 shows the ozone distribution in a vertical plane, along a line that



123°
122°
39°
39°
38
38
37
37°
123
122
20
SACRAMENTO
5
10
15
2½
20
15
STOCKTON
SAN FRANCISCO
OAKLAND
20
10
FARALLON IS
SAN JOSE
2½
5
CONTOUR INTERVAL 1000 ft
0
25 mi
0
25 km

FIGURE 37 PERCENTAGE OF DAYS (1970 - 1972) IN THE SAN FRANCISCO BAY AREA WHEN ONE OR MORE HOURS EQUALED OR EXCEEDED THE FEDERAL 1-HOUR AVERAGE O_x STANDARD OF 0.08 ppm

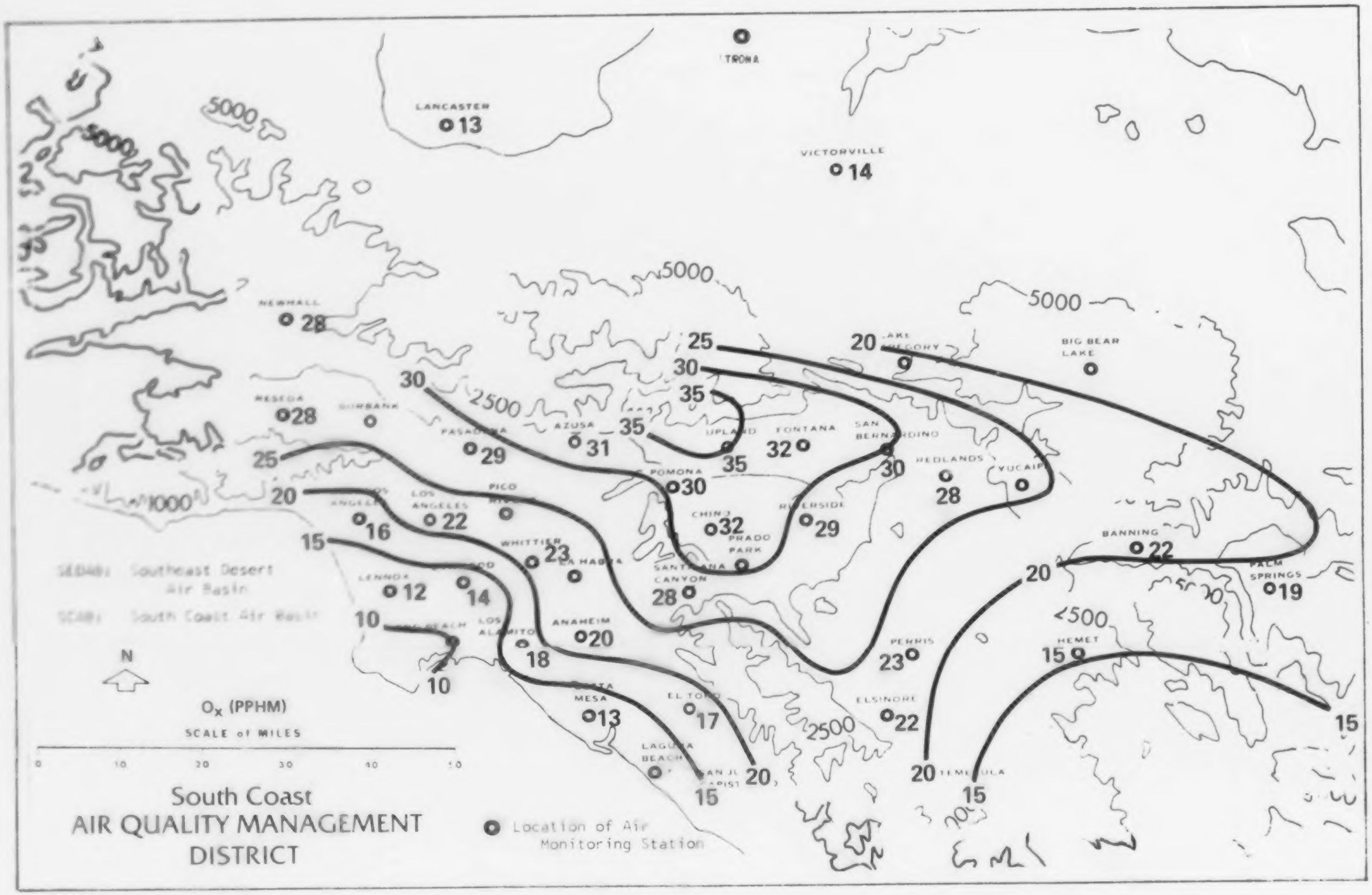

TRONA
LANCASTER 13
VICTORVILLE 14
5000
NEWHALL 28
RESEDA 28
BURBANK
PASADENA 29
AZUSA 31
UPLAND 35
FONTANA 32
SAN BERNARDINO 30
LAKE GREGORY
BIG BEAR LAKE
REDLANDS 28
YUCAIPA
POMONA 30
CHINO 32
PRADO PARK
RIVERSIDE 29
BANNING 22
PALM SPRINGS 19
LOS ANGELES 22
PICO RIVERA
WHITTIER 23
LA HABRA
SANTA ANA CANYON 28
LENNOX 12
LONG BEACH
LOS ALAMITOS 18
ANAHEIM 20
COSTA MESA 13
EL TORO 17
LAGUNA BEACH
SAN JUAN CAPISTRANO
PERRIS 23
ELSINORE 22
HEMET 15
TEMECULA
2500
1000
10
15
20
25
30
35
SEDAB: Southeast Desert Air Basin
SCAB: South Coast Air Basin
N
O_x (PPHM)
SCALE of MILES
0 10 20 30 40 50
South Coast
AIR QUALITY MANAGEMENT
DISTRICT
Location of Air Monitoring Station

FIGURE 38 ONE-PERCENTILE PEAK-HOUR OXIDANT CONCENTRATIONS (PPHM) IN THE LOS ANGELES BASIN

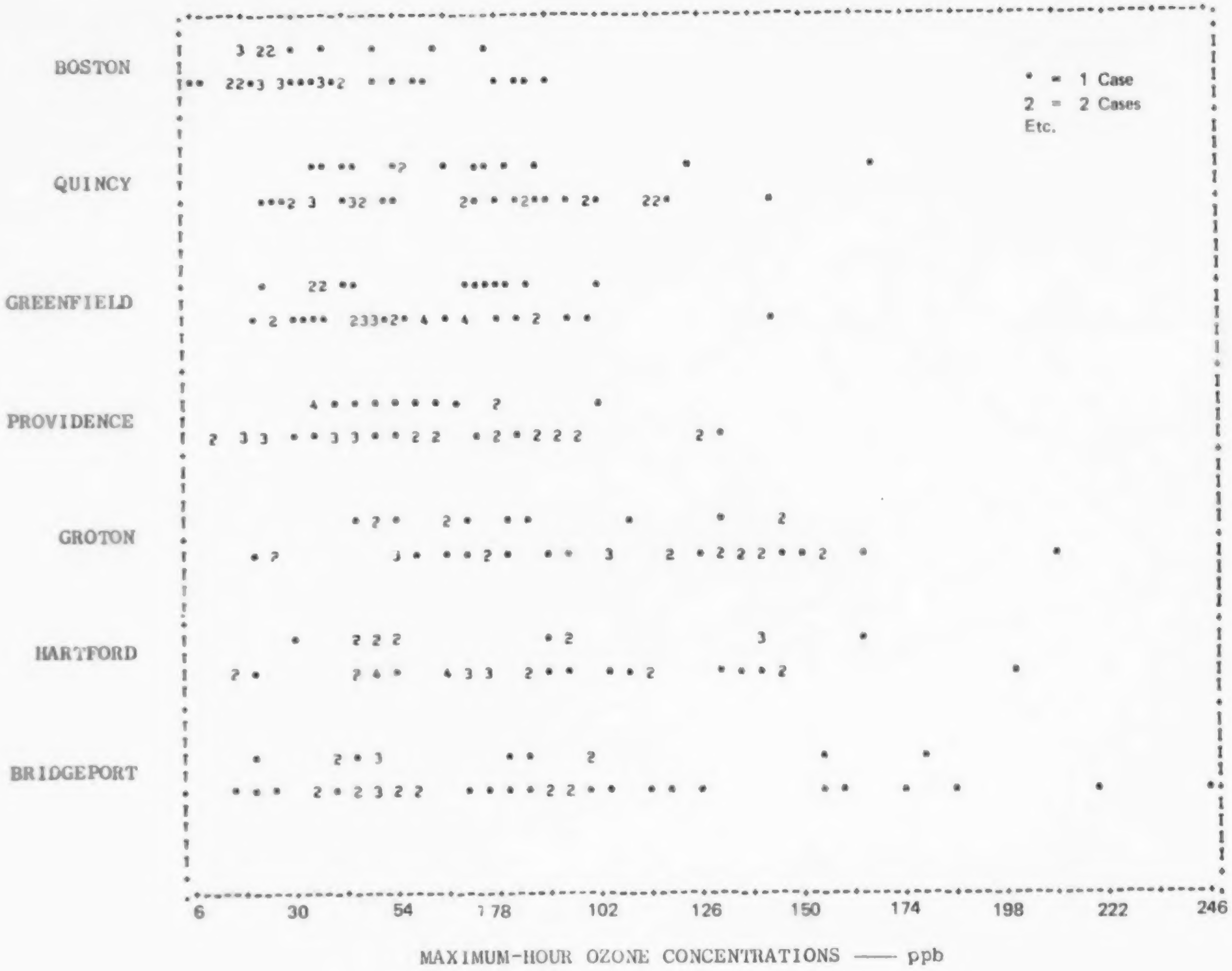


FIGURE 39 OBSERVED MAXIMUM DAILY OZONE CONCENTRATIONS AT SEVEN NEW ENGLAND SAMPLING SITES

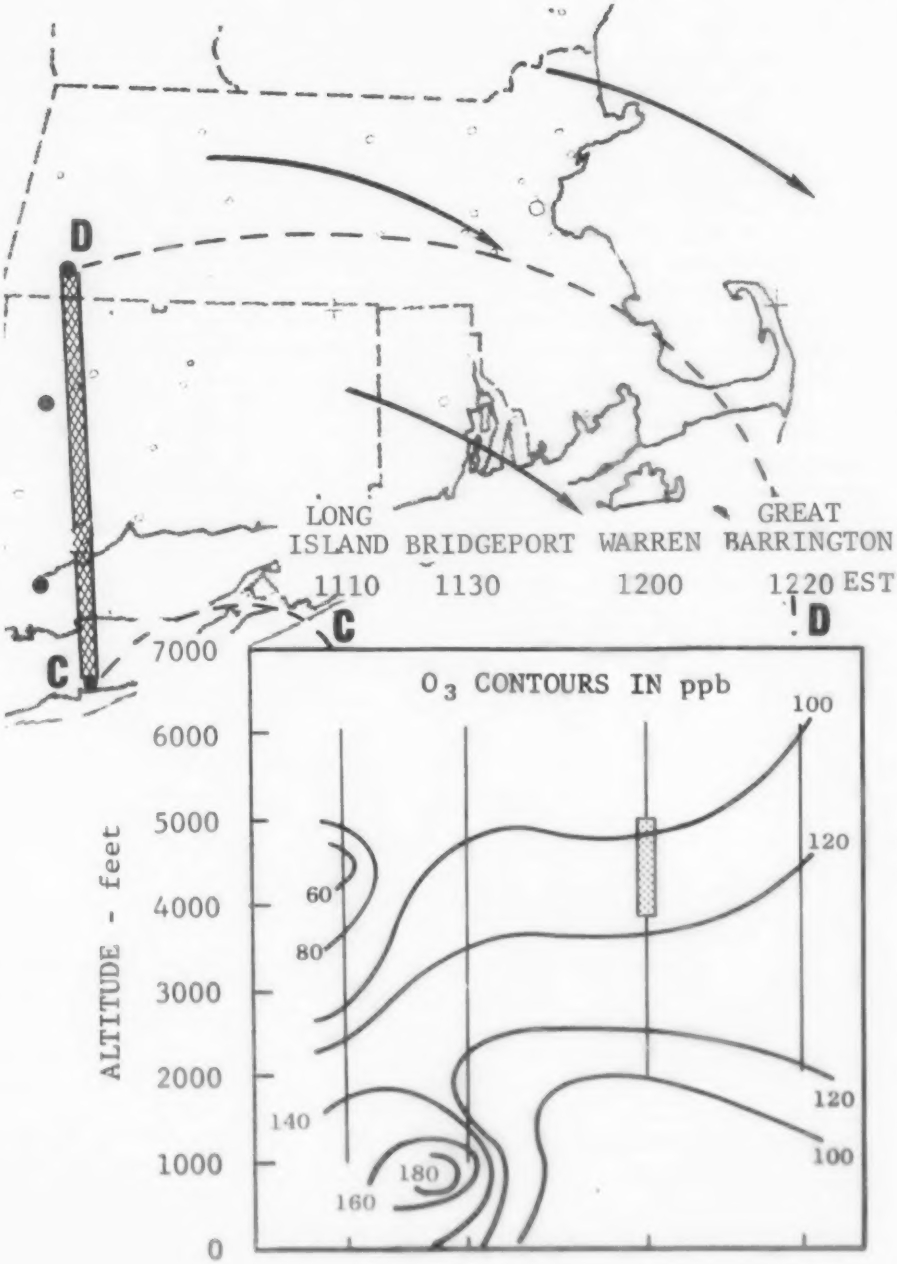


FIGURE 40 VERTICAL CROSS SECTION OF OZONE CONCENTRATION OVER WESTERN CONNECTICUT AND LONG ISLAND, 1110–1220 EST, AUGUST 10, 1975

is nearly north-south. The analysis shows that above Bridgeport, Connecticut the highest concentrations were at an altitude of about 300 m. This elevated plume may have been the result of the difference in chemical reactions between ground level and more elevated layers. At ground level the ozone-producing reactions are partially offset by competing ozone-destroying reactions. In particular, NO released near ground level will quickly combine with the ozone. Eventually the NO_2 produced by this reaction results in increased ozone, but on the shorter term, the net result is a reduction in ozone concentrations near ground level.

Figure 41 shows two cross sections later the same day. It also shows the streamlines for the 850 mb winds at 1900 EST. The cross sections are based on data collected between 1545 and 1715 EST. These analyses show an elevated ozone layer above Bridgeport, Connecticut, where concentrations, exceeded 180 ppb. Over western Long Island Sound they exceeded 140 ppb. If the 850 mb streamlines represent the air motions affecting the ozone transport around this time, then the air that passed over Bridgeport also passed over Groton. If that were the case, the two cross sections indicate a decline in the ozone concentrations from values above 180 ppb to about 125 ppb. At the south end of the cross section, just south of the east end of Long Island, there were very high concentrations aloft--in excess of 230 ppb. The air reaching this area had passed over the Newark and Jersey City regions of New Jersey, then over the south tip of Manhattan and the Queens-Brooklyn areas. The high ozone concentrations aloft seem very likely to have had their genesis in emissions from those upstream regions.

The cross sections shown in Figures 40 and 41, and numerous others, suggest that the ozone producing processes proceed through a rather deep layer above the city. At the lower levels ozone may be destroyed by NO and other processes at the surface, but once the plume passes beyond the edge of the city, mixing processes bring high concentrations down to the surface from aloft. This appears to account for the fact that the high ozone concentrations, at least in very large urban areas, occur at ground level very near the downwind edge of the city. Beyond that point lateral spreading and vertical mixing in combination with destruction at the surface offset the reduced production rates.

Other examples of the buildup of ozone downwind of cities are available. The California Air Resources Board (ARB, 1977) found, in a study conducted at Fresno, California during episode-level days, that there were higher ozone values on the downwind edge of the city than in air entering the city. Figure 42 shows their results as plots of the mean diurnal oxidant concentrations taken at the upwind edge, central business district, and downwind edge of Fresno. The results show the gradient between upwind and downwind stations was most pronounced during the early afternoon hours.

Westberg and Rasmussen (1973) measured ozone concentrations at about 300 m altitude in the vicinity of Houston. Figures 43 and 44 give examples when ozone concentrations were relatively high. The general wind direction is shown in the figures and the flight paths are indicated by the hatched lines. Observed ozone concentrations, in ppb, are indicated at various locations along the flight paths. These concentrations were used as the basis for the isopleth analyses shown in the figures. The increase in ozone concentrations across the city from the upwind to the downwind edge and beyond is apparent in both figures. The location of the maximum concentrations occurs between about 60 and 80 km downwind of the upwind edge of the Houston area.

Martinez and Bach (1977) described ozone plumes downwind of smaller Texas source areas, specifically the petrochemical complexes near Nederland and Port Arthur. In the case that they studied, the maximum concentrations occurred about 75 km downwind of the source area. At the wind speeds prevailing during the period of observation this represented about 3-1/2 hours transport time. This is somewhat less than the 5 to 7 hours discussed earlier. However, the time of the observation (1400 to 1800 local time) and the relatively small source areas may have contributed to the maximum concentration occurring closer to the source than would be the case for larger cities in the early afternoon.

The data collected by the 25 station St. Louis monitoring network of EPA's Regional Air Pollution Study (RAPS) provide a good source of information for determining the location of

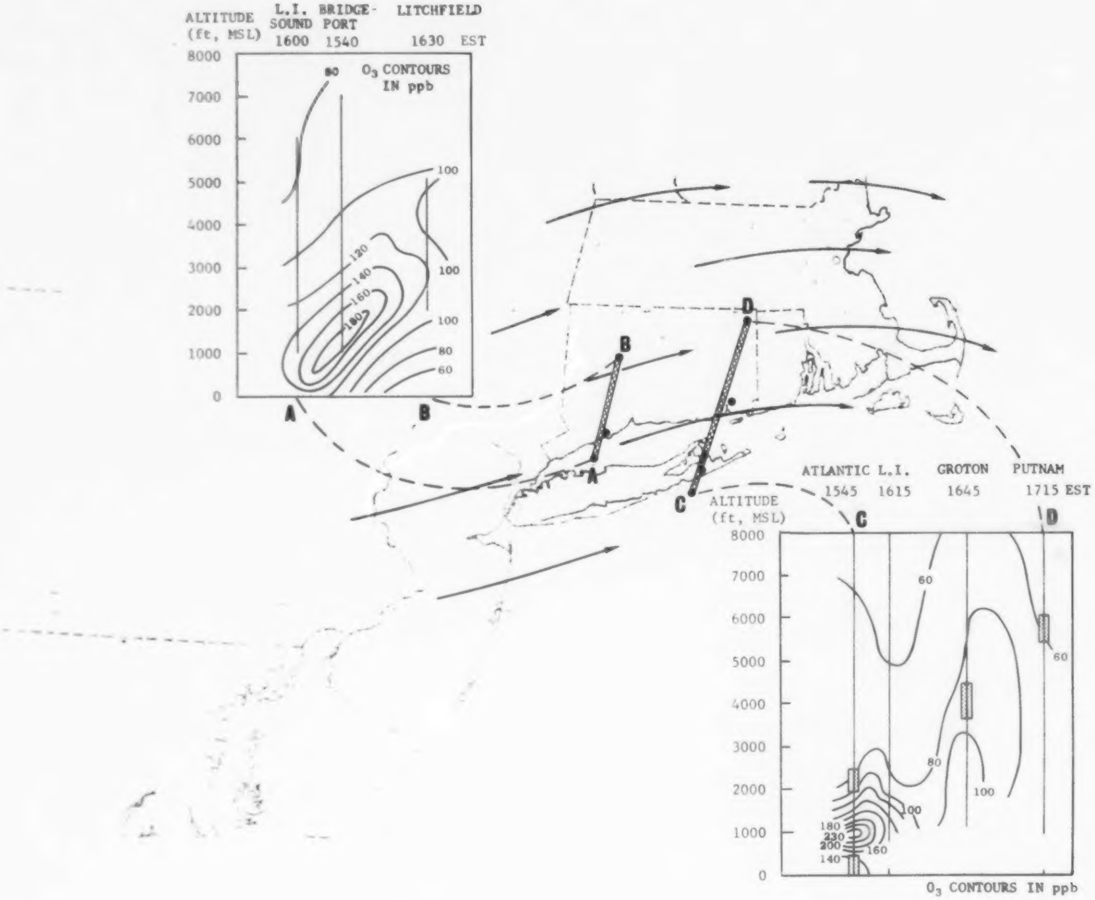
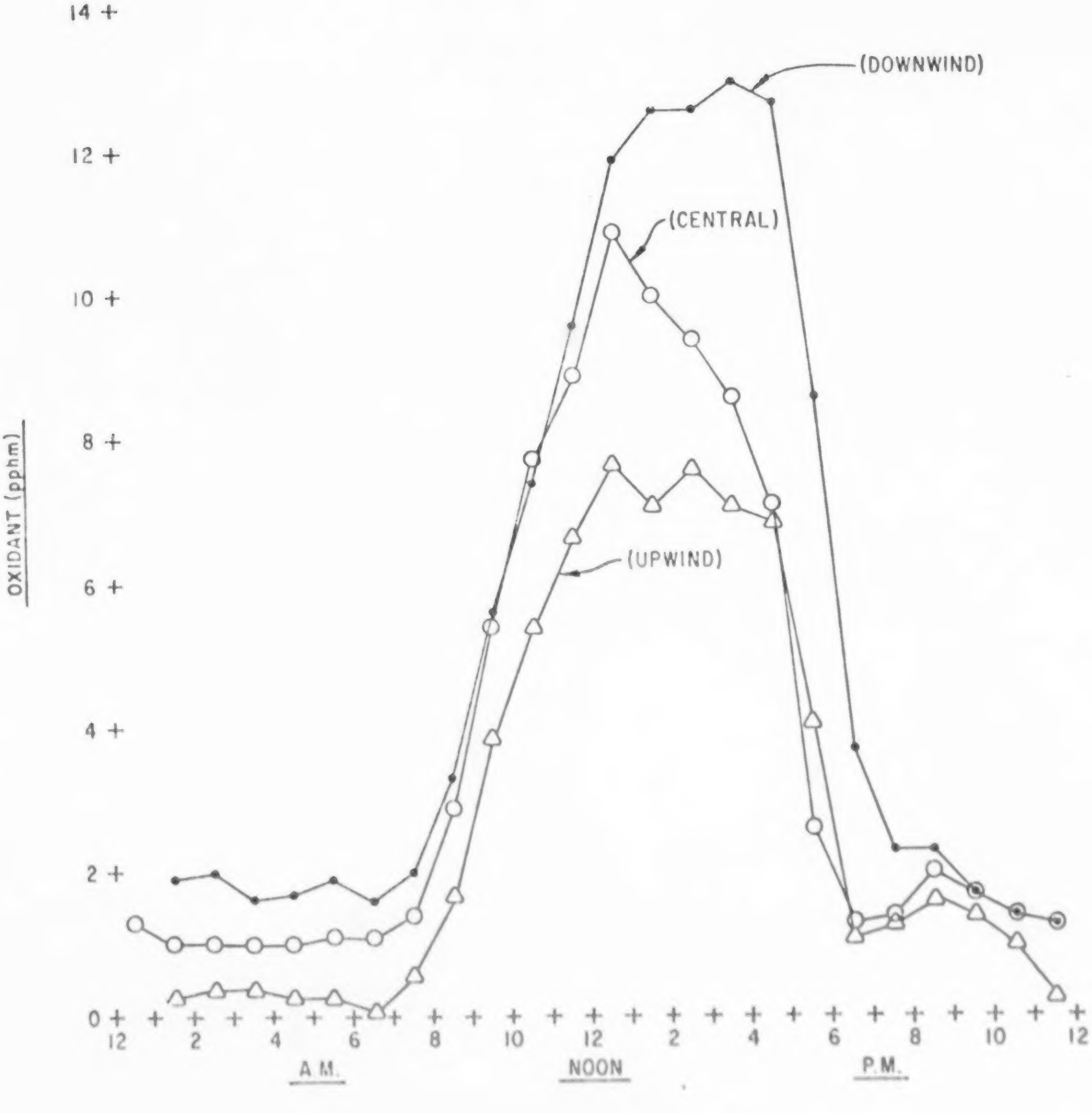
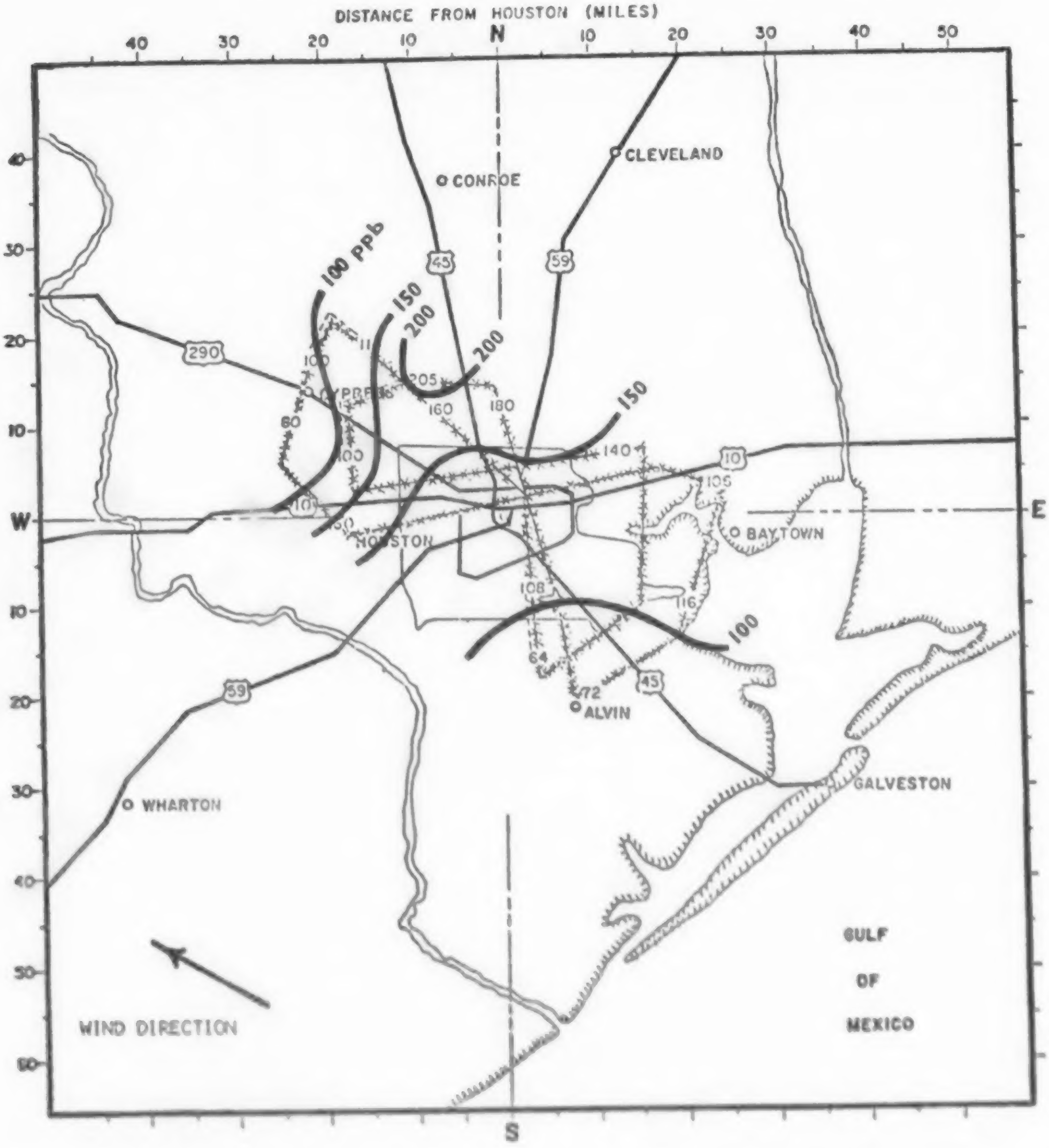

ALTITUDE (ft, MSL)
L.I. SOUND 1600
BRIDGE-PORT 1540
LITCHFIELD 1630 EST
8000
7000
6000
5000
4000
3000
2000
1000
0
O_3 CONTOURS IN ppb
80
100
120
140
160
180
100
100
80
60
A
B
A
B
C
D
ATLANTIC 1545
L.I. 1615
GROTON 1645
PUTNAM 1715 EST
ALTITUDE (ft, MSL)
C
D
8000
7000
6000
5000
4000
3000
2000
1000
0
60
60
80
100
100
180
230
200
140
160
O_3 CONTOURS IN ppb

FIGURE 41 VERTICAL CROSS SECTIONS OVER CONNECTICUT 1545–1715, AUGUST 10, 1975



Source: California Air Resources Board, 1977

FIGURE 42 MEAN DIURNAL OXIDANT PROFILES FOR SEVEN-DAY ADVERSE PERIOD (OCTOBER 6-12, 1976) FOR UPWIND, CENTRAL BUSINESS DISTRICT, AND DOWNWIND SITES AT FRESNO, CALIFORNIA



DISTANCE FROM HOUSTON (MILES)
40
30
20
10
N
10
20
30
40
50
40
30
20
10
W
E
10
20
30
40
50
60
S
CLEVELAND
CONROE
45
59
100 ppb
150
200
200
150
100
290
100
CYPRESS
80
100
11
205
160
180
140
10
105
BAYTOWN
10
50
HOUSTON
108
116
64
72
ALVIN
45
59
WHARTON
GALVESTON
GULF
OF
MEXICO
WIND DIRECTION

FIGURE 43 OZONE CONCENTRATIONS AT ABOUT 300 M IN THE HOUSTON AREA, 1300–1600 (CST) OCTOBER 8, 1973

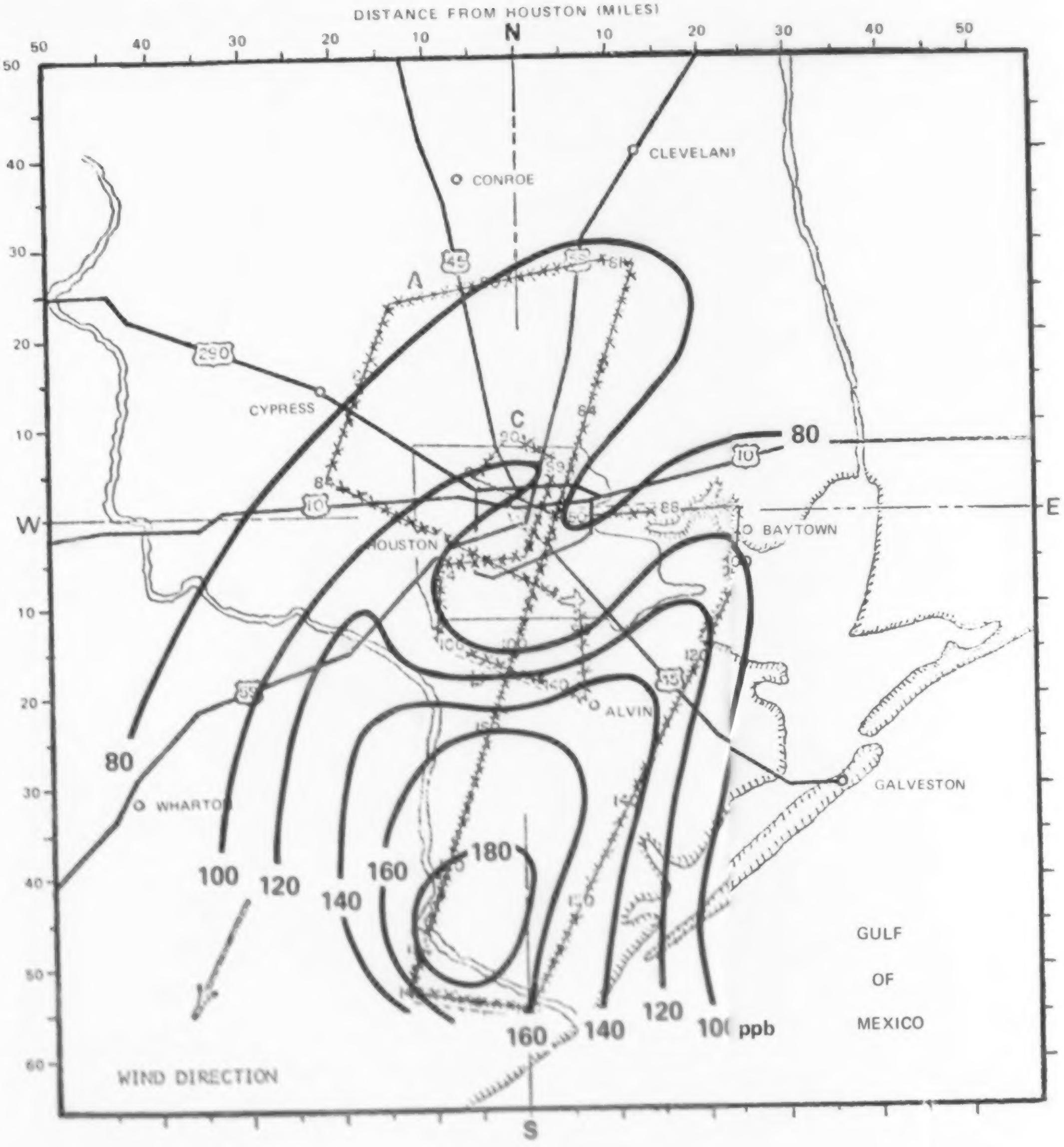

DISTANCE FROM HOUSTON (MILES)
50
40
30
20
10
N
10
20
30
40
50
W
E
S
CONROE
CLEVELAND
CYPRESS
HOUSTON
BAYTOWN
ALVIN
GALVESTON
WHARTON
A
C
45
290
10
59
35
80
80
100
120
140
160
180
160
140
120
100 ppb
GULF
OF
MEXICO
WIND DIRECTION

FIGURE 44 OZONE CONCENTRATIONS AT ABOUT 300 m IN THE HOUSTON AREA, 1300-1600 (CST) OCTOBER 17, 1973

oxidant maxima and the effects of NO emissions in a city. Objective analyses of ozone and NO_2 concentration distributions were prepared by computer for the afternoon hours of 13 days in 1976. The days were chosen because at least one of the monitoring stations observed ozone concentrations of twice the standard, i.e. 160 ppb. Examples of these analyses are given in Figure 45 . The objective analysis procedure begins by interpolating concentration values for a regularly spaced set of 361 grid points. These grid point values, obtained from the 25 irregularly spaced monitoring sites, then provide the framework for generating computer isopleths of pollutant concentration. The interpolation scheme uses the first-degree, least-squares fit of a polynomial surface to the data from the 5 nearest observing stations, weighted inversely with distance (Endlich and Mancuso, 1968; Mancuso and Endlich, 1973). The objective analyses smooth the data somewhat. This is desirable for our purposes, where we are attempting to locate general features of the distributions of the pollutants. The winds are represented in the figures by vectors pointing in the direction in which the wind is blowing and centered on the monitoring site. The length of a wind vector is proportional to the wind speed and shows the distance that would be traveled in one hour at that speed. The winds show considerable variation in time and space. The ozone maximum occurred in the downwind direction in 9 of the 13 cases. In those 9 cases, the distance from the upwind edge of the city to the ozone maximum varied from about 4 to 7 times the distance corresponding to one hour's air movement for the typical noon wind. The maximum concentrations generally occurred in the early- to mid-afternoon. In one instance the maximum ozone concentration appeared to be upwind of the city, at least for the wind directions at the time of that maximum. However, there had been considerable variation in wind direction through the day, so that the maximum may not have been truly upwind.

The example shown in Figure 45 has the ozone maximum located in about the place where it might have been expected on the basis of the high temperature wind rose for St. Louis, given in Figure 16. This was not always the case. Comparably high concentrations were found to the north, closer to the city and to the northeast. On one or two occasions, somewhat lower ozone maxima were observed to the west of the city. On one occasion, to be discussed later, higher concentrations were observed south of St. Louis. These exceptions to the rule do not necessarily invalidate it, but they do suggest that a single monitor to locate the maximum ozone concentrations is likely to be inadequate. Nevertheless, a station located according to the rules given here would have observed concentrations near the maxima on many of those days when the highest oxidant concentrations occurred.

6.3.2.3. Destruction of Ozone by Urban NO Emissions

Figure 45 illustrates the tendency for lower ozone concentrations to occur over the city. At 1400 and 1600, there was a trough in the ozone concentration distribution over St. Louis, while there was an increase toward the downwind direction, especially at 1400. On the other hand, NO_2 concentrations were highest near the downwind edge of the city for most of the afternoon.

October 1 and 2, 1976, provide better examples of the destruction of ozone over the city. Figure 46 shows the NO, NO_2, and ozone concentrations in the St. Louis vicinity for the afternoon and early evening hours of October 1, a day of very light winds. Precursors and the resulting ozone tended to accumulate near the city. At noon, virtually all of the NO_x was present as NO_2; the figure shows no NO concentrations exceeded 2 pphm. The concentrations of NO_2 were at a maximum over the city. The maximum ozone concentrations were observed just outside the city to the northwest. For the next four hours the NO concentration remained low while the NO_2 and ozone patterns drifted very slowly toward the southeast. By 1800 the air motion had reversed itself, carrying the NO_2 and ozone accumulations back toward the city. The NO concentrations rose sharply in the late afternoon and early evening in response to the afternoon rush hour. The effect of the city was dramatically apparent at 1800. While NO and NO_2 had their maxima nearly centered over the city, there is a deep minimum in the ozone field over the city where it was generally less than 2 pphm. Just to the south, outside the city, concentrations in excess of 20 pphm were observed. To the northeast, also outside the city,

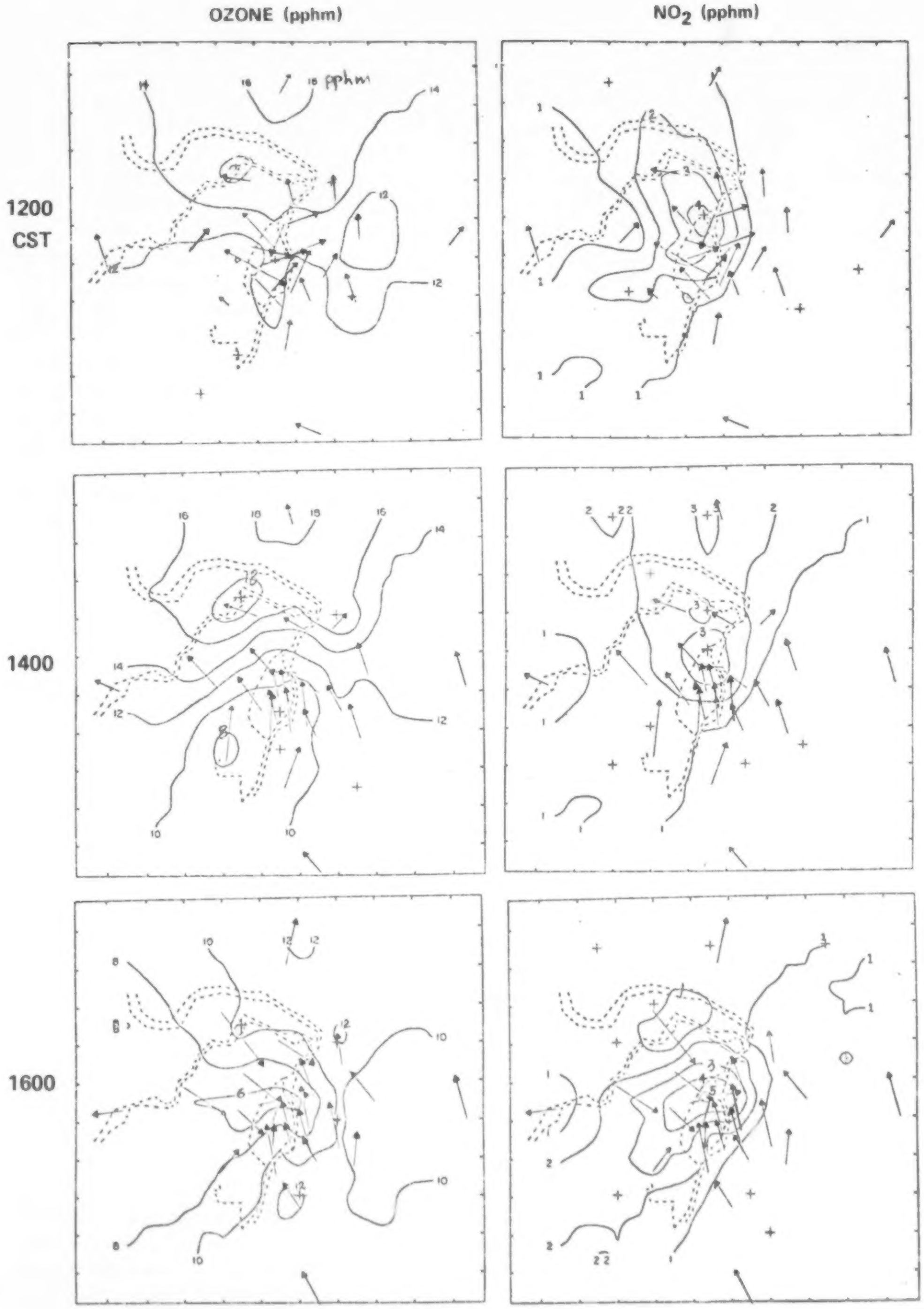

OZONE (pphm)
NO$_2$ (pphm)
1200
CST
1400
1600
18 pphm
14
12
16
10
8
6
3
2
1
5

FIGURE 45 OZONE AND NO$_2$ CONCENTRATION PATTERNS IN THE ST. LOUIS AREA DURING THE AFTERNOON OF AUGUST 25, 1976

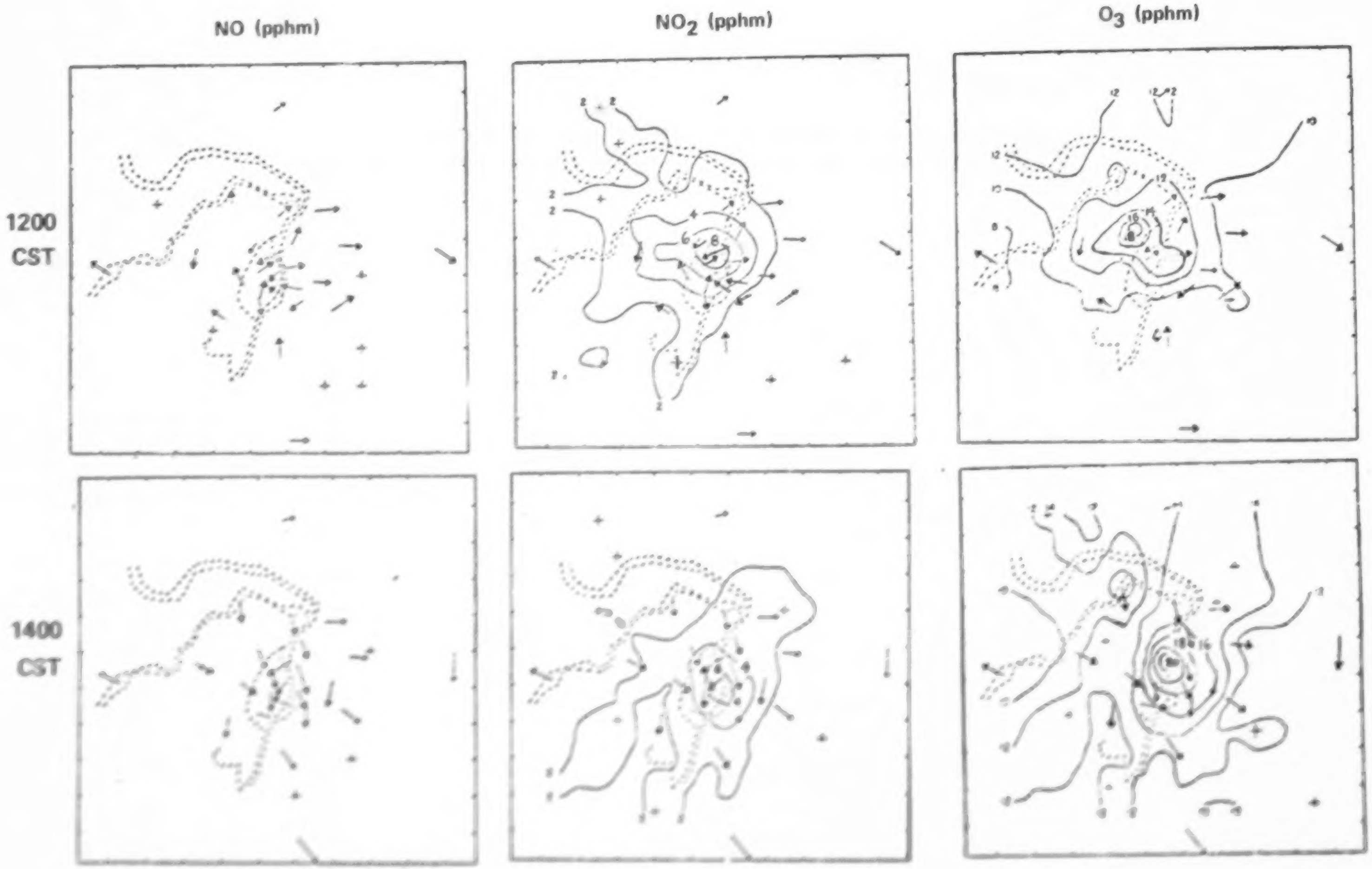

NO (pphm)
NO$_2$ (pphm)
O$_3$ (pphm)
1200 CST
1400 CST

FIGURE 46 OZONE, NO AND NO$_2$ CONCENTRATIONS (PPHM) IN THE ST. LOUIS AREA DURING THE AFTERNOON OF OCTOBER 1, 1976

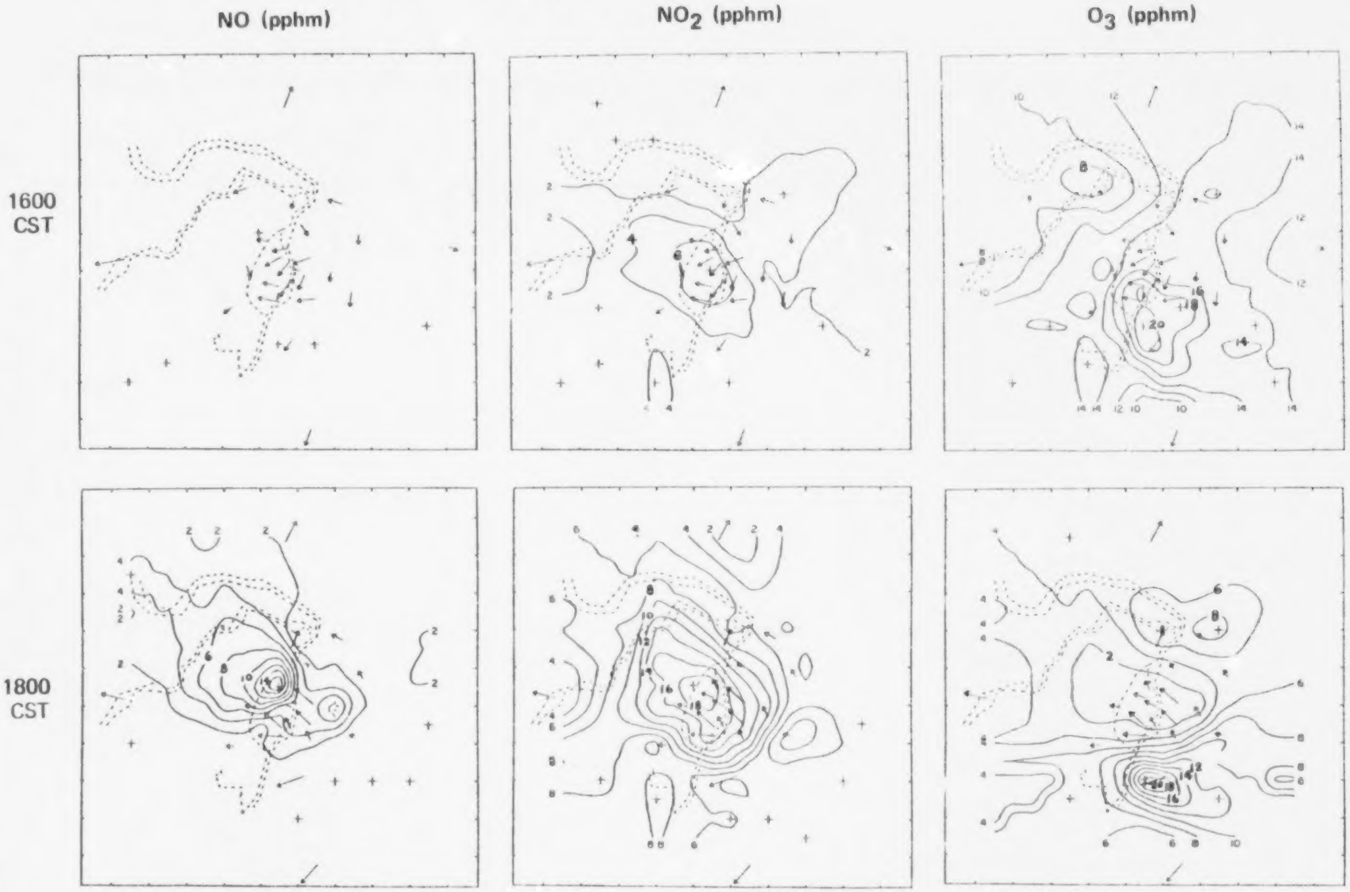

NO (pphm)
NO2 (pphm)
O3 (pphm)
1600 CST
1800 CST

FIGURE 46 OZONE, NO AND NO_2 CONCENTRATIONS (PPHM) IN THE ST. LOUIS AREA DURING THE AFTERNOON OF OCTOBER 1, 1976 (Concluded)

concentrations in excess of the federal standard were found. Obviously, the monitoring of maximum ozone concentrations will require a station outside the major urban emissions area.

Figure 47 shows that the NO concentrations remained very high over the city, throughout the night. The concentrations of NO_2 also remained high and were centered over the major emissions area. Ozone concentrations at ground level were less than 2 pphm throughout most of the area during the early morning hours. The accumulated NO remained in the area until after sunrise. As shown in Figure 47 the NO concentrations had dropped to about 12 pphm by 0800 on this Saturday morning. By 1000 (not shown in the figure), they were below 2 pphm, where they remained throughout most of the day. Between 0800 and 1400 the winds were light and variable but tended toward the northeast, carrying precursors with them. At 1400, the maximum ozone concentrations were northeast of the city. Between 1400 and 1600 the light winds tended to reverse themselves and carry the ozone back toward the city. The result was a pattern similar to that observed the preceding afternoon. At 1800 the ozone concentrations over the city itself were generally less than 2 pphm while those north and south of the city reached 10 to 12 pphm. Again, the bite taken out of the ozone pattern by the NO emissions provides considerable support to the recommendation that maximum ozone concentrations not be sought within the urban area itself.

6.4. Local Effects and the Selection of Specific Sites

The major types of site for the photochemical pollutants are supposed to represent large areas. This means that the site should be selected so that it is in an area of small gradients and that the readings are not affected by small changes in the location of the station. This criterion will be met if the site is such that no single source contributes disproportionately to the readings obtained there, but rather that the readings represent the sum of many small contributions from numerous individual sources. In the case of the photochemical pollutants, sinks can be as important as sources. Wherever possible, we have tried to quantify the effect of sources and sinks so that we could choose some acceptable effect and then specify the conditions under which that level would not be exceeded. If the reader disagrees with our choice of acceptable level of influence, another can be chosen and the same methods applied to revise the siting criteria accordingly.

6.4.1. Effects of Obstructions

The effects of obstructions and nearby surfaces may not be very important for hydrocarbon monitoring, but it is known that ozone, and perhaps the oxides of nitrogen, can be destroyed on contact with surfaces. It is important that sampling be done at a location where the air has had as little contact with nearby surfaces as possible. Figure 48 is a schematic representation of airflow around a sharp edged building based on the work of Halitsky (1961), Briggs (1973), and Gifford (1973). The figure shows that air in the cavity zone will make considerable contact with the building. Air outside the cavity zone will have passed over the building with minimal contact. It is assumed that the flow around other obstructions is similar to that shown in Figure 48. According to Briggs (1973), the cavity zone extends to roughly 1-1/2 building heights downwind of the building. Using this as a guide, we have recommended that the sampler be separated from any obstruction by at least twice the height of the obstruction above the inlet. Figure 48 also illustrates why it has been recommended that inlets along the side of a building be avoided. There is airflow up the side of the building which has considerable contact with the building and presents a substantial possibility for destruction of a fragile pollutant.

The inlet for sampling must extend above the roof of the building to avoid the complicated airflow within the cavity zone. If the building housing the instruments is rather small, say about 2 meters high, then an extension of the inlet above the roof by a distance of about 1-1/2 meters should be sufficient. For taller buildings it may not be possible to avoid the cavity zone on top of the building without using an inlet line that is so long that it will introduce pollutant losses of its own. If sampling from the top of a tall building cannot be avoided, then the wisest course will be to place the inlet toward the upwind side of the building. Upwind again refers to the wind direction for the most important photochemical conditions.

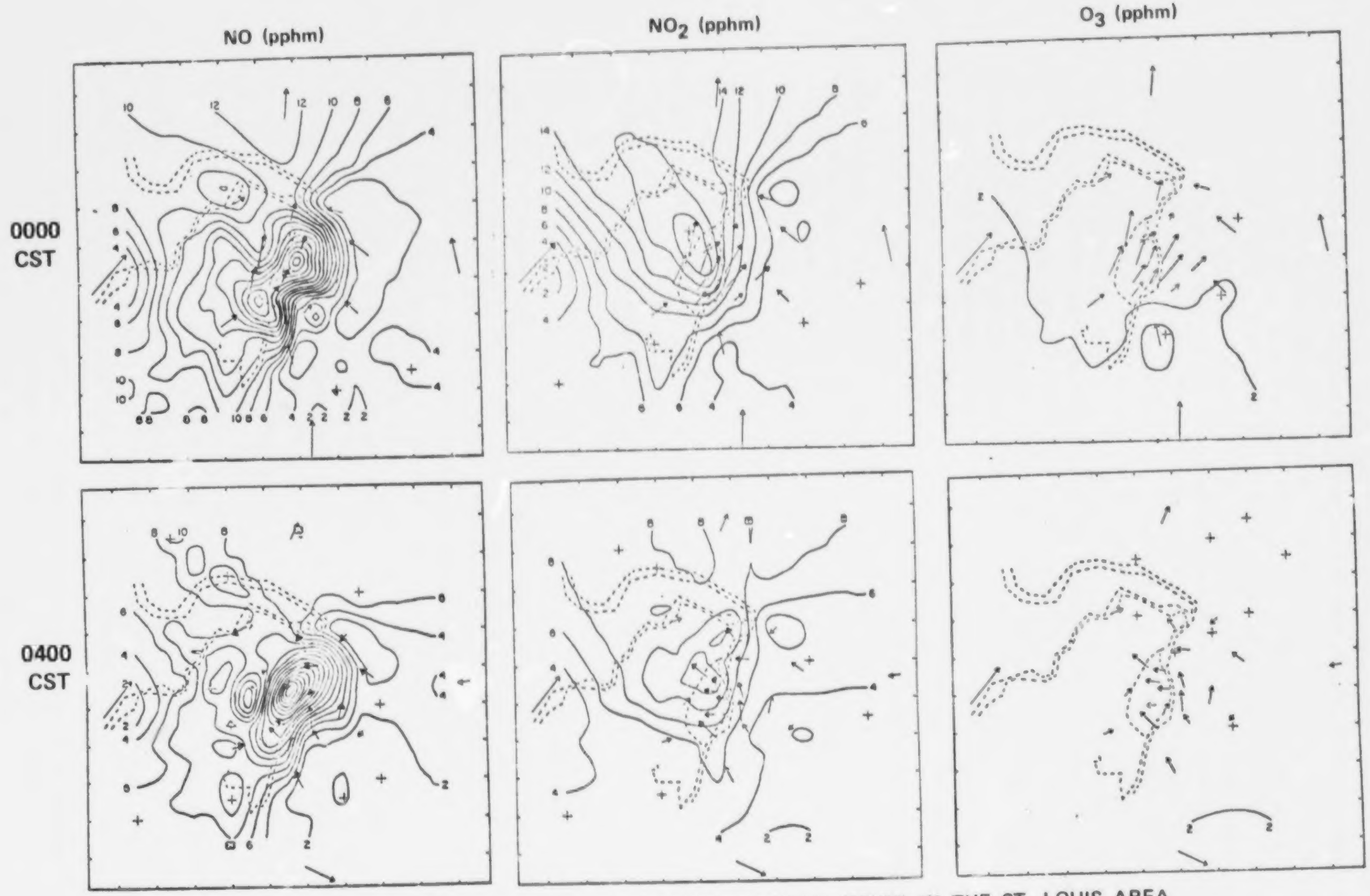

NO (pphm)
NO$_2$ (pphm)
O$_3$ (pphm)
0000 CST
0400 CST

FIGURE 47 OZONE, NO AND NO$_2$ CONCENTRATIONS (PPHM) IN THE ST. LOUIS AREA ON OCTOBER 2, 1976

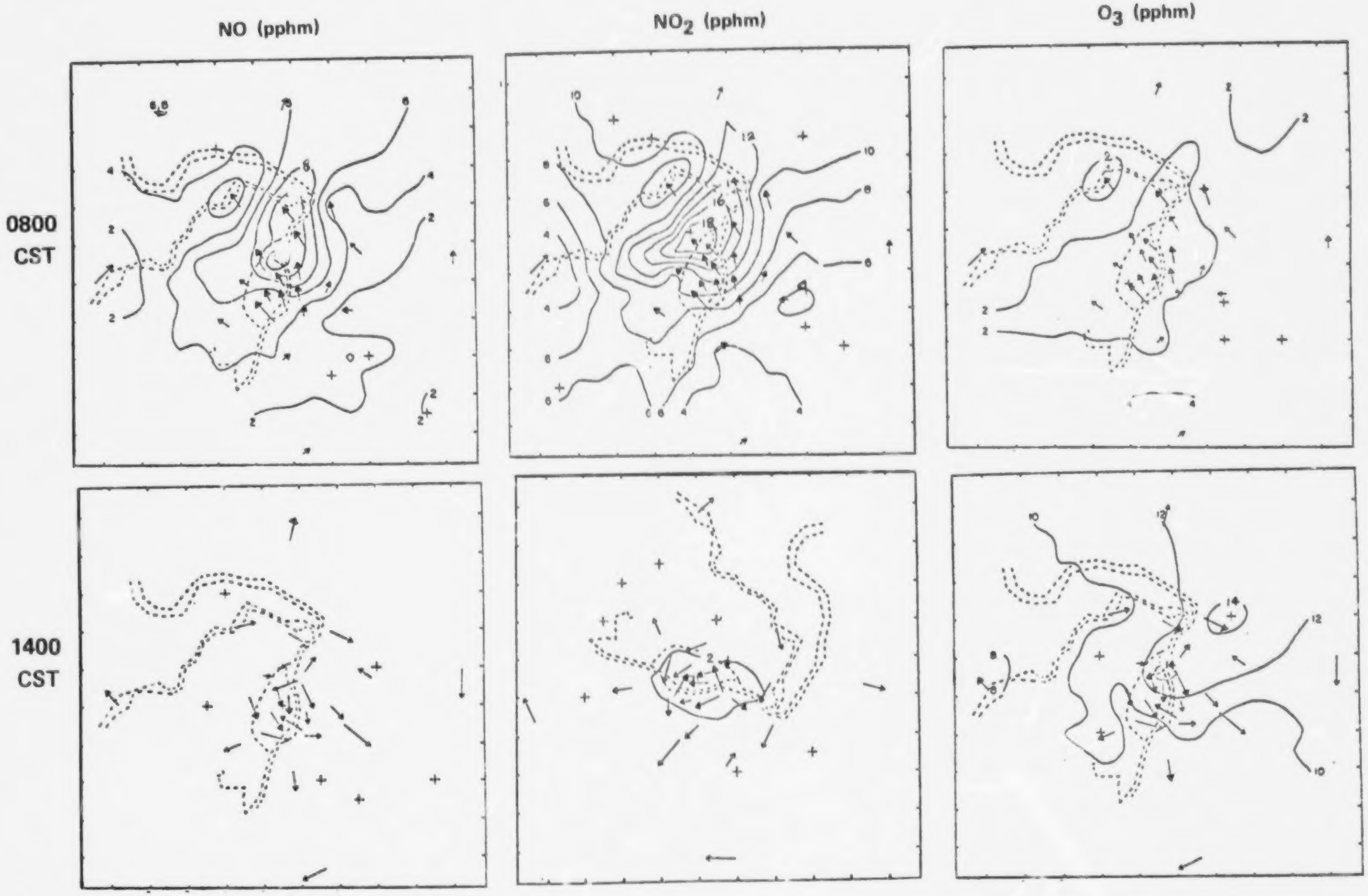

NO (pphm)
NO$_2$ (pphm)
O$_3$ (pphm)
0800
CST
1400
CST

FIGURE 47 OZONE, NO AND NO$_2$ CONCENTRATIONS (PPHM) IN THE ST. LOUIS AREA ON OCTOBER 2, 1976 (Continued)

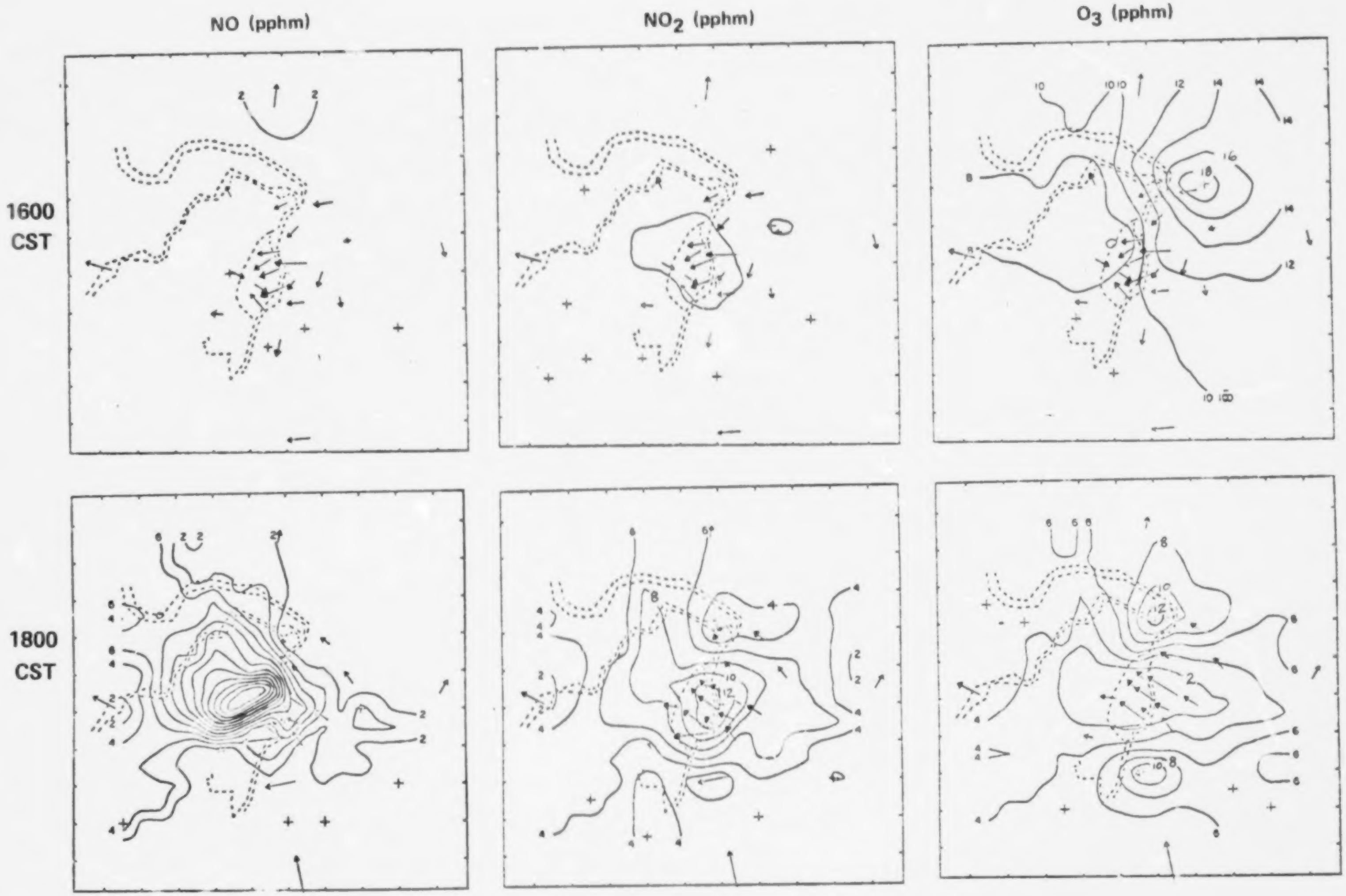

NO (pphm)
NO2 (pphm)
O3 (pphm)
1600 CST
1800 CST

FIGURE 47 OZONE, NO, AND NO_2 CONCENTRATIONS (PPHM) IN THE ST. LOUIS AREA ON OCTOBER 2, 1976 (Concluded)

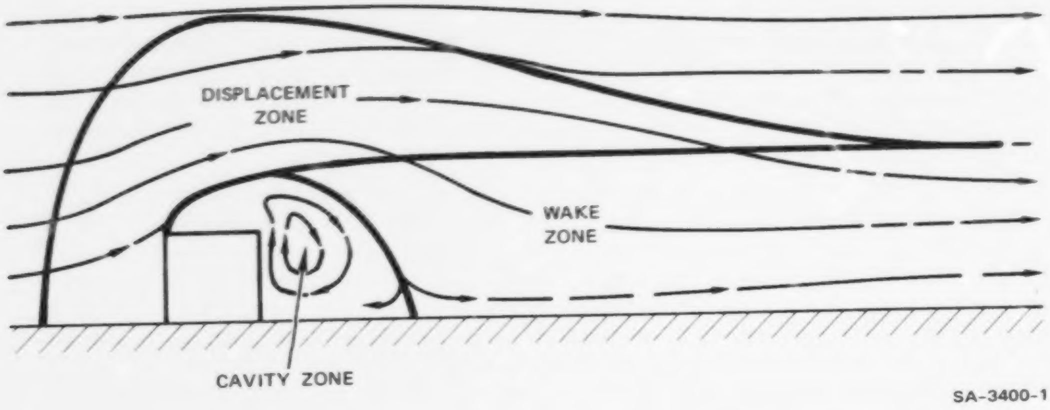

DISPLACEMENT ZONE
WAKE ZONE
CAVITY ZONE
SA-3400-1

FIGURE 48 SCHEMATIC REPRESENTATION OF THE AIRFLOW AROUND AN OBSTACLE

6.4.2. Separation from Roadways

Streets and roadways are important sources of possible interference with the measurement of pollutants. In the case of NMHC and total oxides of nitrogen, they can be considered as simple sources and their contributions can be evaluated by rather straightforward means. In the case of NO_2 and ozone, the effects are more complicated. Ozone will be removed by the NO emitted along roadways and hence the roadway will act as a sink. At the same time that the NO is reacting to remove ozone, it is also being transformed into NO_2. In the following sections the magnitude of the effects are estimated and related to the separation between roadways and monitors.

6.4.2.1. Nonmethane Hydrocarbons

Figure 49, from Dabberdt and Sandys (1976), shows the concentration normalized for wind speed and emission rate, at different distances from a roadway, for different wind directions relative to that roadway. The figure was obtained by assuming an infinitely long section of roadway and calculating the concentrations using the HIWAY computer model (Zimmerman and Thompson, 1975). The figure shows that there is a maximum concentration at each distance for rather small angles between the wind and the roadway. Those maximum concentrations can be combined with estimates of emission rate along the road and a minimum wind speed to estimate the maximum concentrations likely to occur at a given distance from the road. The slightly stable condition represented in Figure 49 will provide fairly conservative (i.e. high) estimates of the roadway contribution.

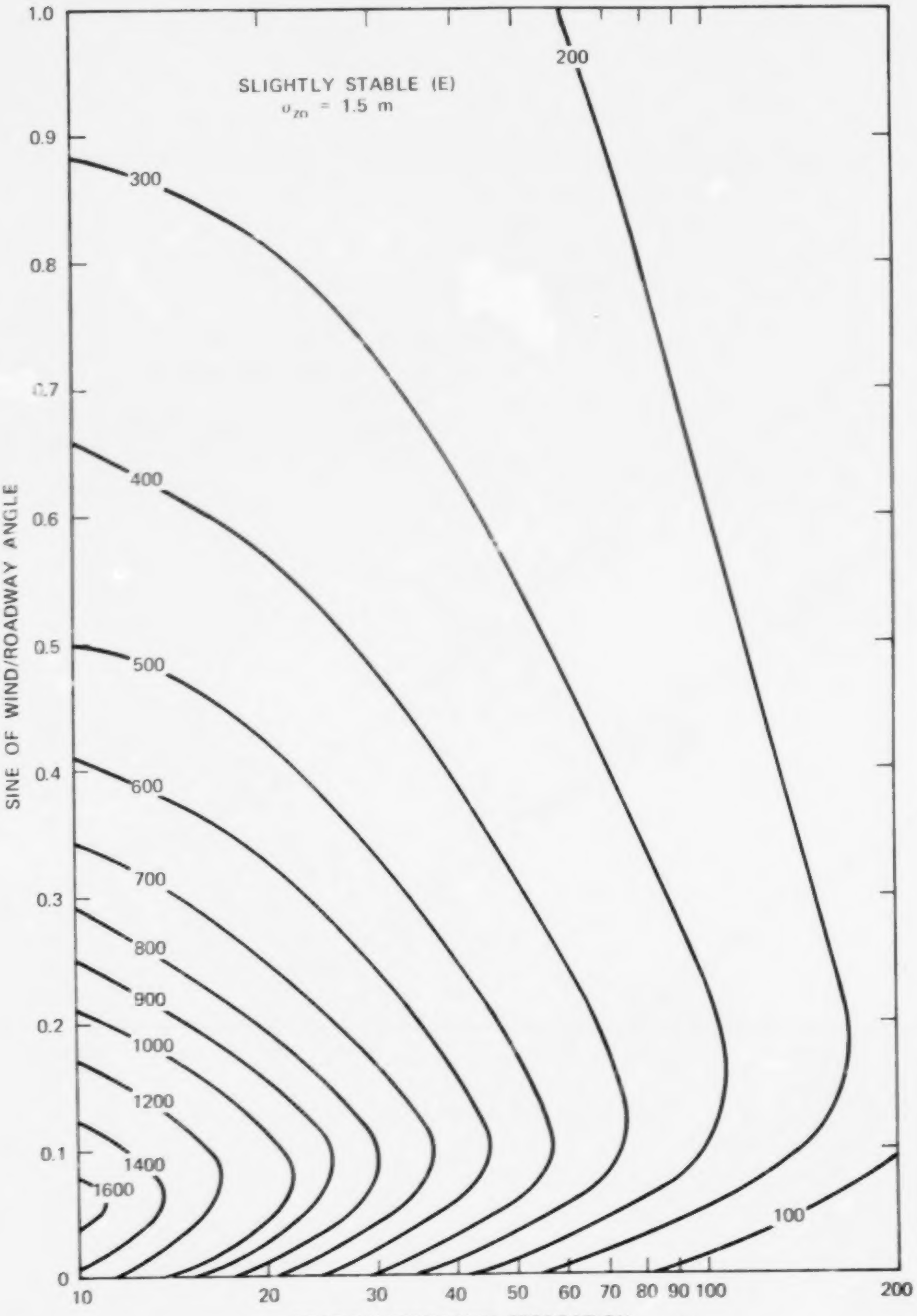
Figure 50 was derived from Figure 49 and it shows the maximum concentrations to be expected at different distances from a roadway for three different average daily traffic (ADT) loadings. The figure was prepared assuming a 1 m s^{-1} wind speed (u), and emission rates (Q) of 4 g mi^{-1} for oxides of nitrogen and NMHC. Peak hour traffic was used to derive the figure; it was assumed that peak hour traffic was equal to 10% of the ADT. It can be seen from Figure 50 that the maximum contribution from roadways can be kept below about 8 pphm, or about a third of the 24 pphm standard, if the separations shown in Figure 8 are adhered to. If the NMHC monitor were collocated with an NO/NO_2 monitor, and the minimum setbacks specified for those pollutants were followed, then according to Figure 50, the traffic contribution to observed NMHC concentrations would only be increased to 9 or 10 pphm at worst. If attention is paid to the direction of the roadway relative to common wind directions, the effect of the road can be further reduced.

6.4.2.2. Nitrogen Dioxide and Ozone

During the daytime there is a tendency for the concentrations of ozone, NO, and NO_2 to be in an equilibrium described by the following equation (see e.g., Calvert, 1976):

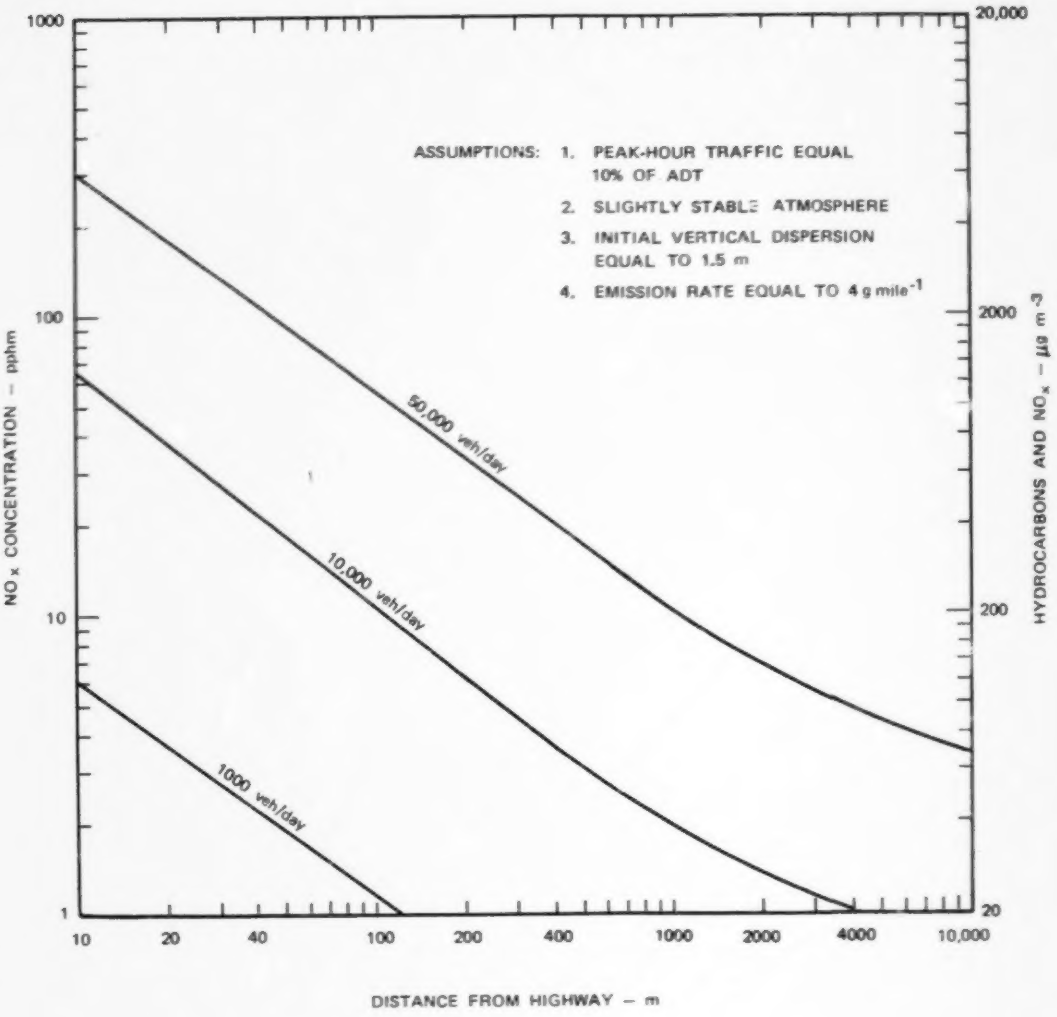
$$[O_3] = \frac{k_1}{k_3} \cdot \frac{[NO_2]}{[NO]} \qquad 1$$

where the brackets indicate concentrations of the enclosed species and the constants, k1, k3, refer respectively to the reactions rates of: (1) the photolytic decomposition of NO_2 into atomic oxygen and NO; and (2) the reaction of ozone with NO to form NO_2 and molecular oxygen. This equilibrium takes a minute or two to be established, so shorter term measurements in the vicinity of NO sources will not usually satisfy the equation. However, the equilibrium provides a good description over longer averaging periods. Figure 51 is a scatter diagram of the product of [NO] and $[O_3]$ versus $[NO_2]$ at RAPS stations in St. Louis for hour averaged observations (0900-1000 CST, on October 1, 1976). The slope of the line of best fit is an estimate of the ratio of k_1/k_3 for the hour. The slope is 0.96 pphm; the intercept is 0.50 $pphm^2$--very nearly



SOURCE: Dabberdt and Sandys, 1976

FIGURE 49 VALUES OF Cu/Q ($10^{-3}m^{-1}$) FOR VARIOUS ROADWAY/RECEPTOR SEPARATIONS AND WIND/ROADWAY ANGLES; INFINITE LINE SOURCE



ASSUMPTIONS: 1. PEAK-HOUR TRAFFIC EQUAL 10% OF ADT
2. SLIGHTLY STABLE ATMOSPHERE
3. INITIAL VERTICAL DISPERSION EQUAL TO 1.5 m
4. EMISSION RATE EQUAL TO 4 g mile^{-1}

FIGURE 50 MAXIMUM ROADWAY CONTRIBUTION TO CONCENTRATION AT DIFFERENT DISTANCES

zero. The correlation is better than 0.98. Assuming that k_1 is constant throughout the area, an assumption which implies uniform insolation over the area, the validity of the equilibrium assumption for hour-average data seems well established. Hours other than that shown in Figure 51 were tested with generally similar results; however, when NO concentrations were too low to be measured reliably, then the slope--and the ratio k_1/k_3--could not be determined very well.

The equilibrium relationship provides a valuable tool for estimating the impact of NO sources on ozone and NO_2 concentrations during the daytime. If we also assume that any increase in NO_2 (ΔNO_2) in the vicinity of an NO source is caused by the reaction of NO with O_3, then

$$\Delta[O_3] = -\Delta[NO_2] \qquad 2$$

Finally, it can be assumed that all the NO introduced by a source will appear as either NO or NO_2 when equilibrium is established. For the shorter term effects occurring near an NO source, the more complicated reactions leading to other nitrogen containing compounds are not important.

The original, or upwind, state is described by the steady-state equation

$$[O_3] = C\frac{[NO_2]}{[NO]} = C\frac{[NO_x] - [NO]}{[NO]} \qquad 3$$

where $C = k_1/k_3$ and $[NO_x] = [NO] + [NO_2]$. The new condition after the introduction of NO and the reestablishment of the steady state are:

$$[O_3]_{new} = C\frac{[NO_2]_{new}}{[NO]_{new}}$$

$$\Delta[O_3] + [O_3] = C\frac{[NO_2] + \Delta[NO_2]}{[NO] + \Delta[NO]}$$

$$= C\frac{[NO_2] + \Delta[NO_2]}{[NO] + \Delta[NO_x] - \Delta[NO_2]} \qquad 4$$

The net changes in $[O_3]$ and $[NO_2]$, i.e. Δ $[O_3]$ and $\Delta[NO_2]$ are numerically equal, but of opposite sign. This is because we have assumed that the new NO_2 all comes from the oxidation of NO by O_3. The changes in O_3 and NO_2 concentration are of interest in assessing the effects on the ambient concentrations of the NO added from the roadway. The following definition can then be used:

$$X = \Delta[O_3] = -\Delta[NO_2]$$

Substituting from Equation (5) into Equation (4) and rearranging gives

$$X^2 + \{[O_3] + \Delta[NO_x] + [NO] + C\}\, x + \Delta[NO_x].[O_3] = 0 \qquad 6$$

Equation (6) is a simple quadratic equation that can be solved for X, i.e. the change in ozone and NO_2 concentrations. It requires knowledge of the amount of NO added--$\Delta[NO_x]$--of

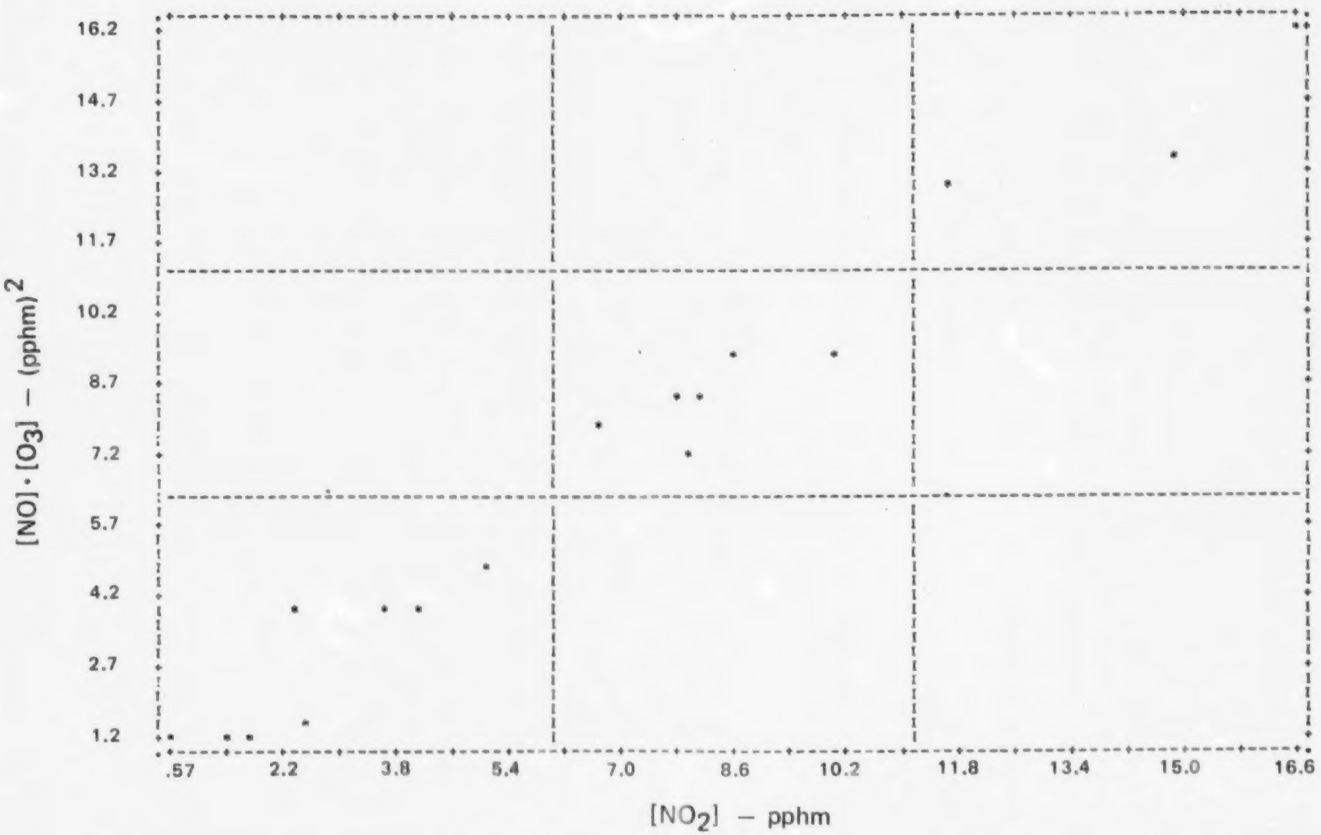


FIGURE 51 SCATTERGRAM OF THE PRODUCT OF NO AND O_3 CONCENTRATIONS VERSUS NO_2 CONCENTRATION AT 17 ST. LOUIS SITES, OCTOBER 1, 1976, 1000 CST

the original conditions--$[O_3]$, [NO], and $[NO_2]$-- and of the current value of k1 so that C = k_1/k_3 can be evaluated. In this model, the oxides of nitrogen are conservative, so relatively simple methods can be used to assess the contribution of the roadway at various locations. Once the change in NO_x concentration, $\Delta[NO_x]$, caused by the roadway is evaluated, for example from Figure 50, then the effects on ozone and NO_2 concentration can also be estimated.

The model discussed above assumes that the quasi-steady state condition prevails. The reactions occur relatively quickly, but not so quickly that the steady state condition will always be a valid assumption. However, the model is still useful for the purposes of evaluating roadway effects on ozone and NO_2 concentrations, because it provides a relatively conservative estimate. The estimates provided by the model will generally be greater than the actual changes in NO_2 and ozone when the adjustment to the steady state condition is not complete.

Equation (6) was solved and graphed for three values of initial ozone concentration, ranging from 80 to 240 ppb, and four values of initial NO concentrations, 1, 30, 60 and 100 ppb. Three values of k_1/k_3 were also considered. Figure 52 shows the results for two values of k_1/k_3, 0.5 and 2. The change in ambient ozone concentration is plotted versus the change in NO_x concentration when the NO_x is added as NO.

It is apparent from Figure 52 that when ambient NO concentrations are very low, the introduction of large amounts of NO_x will remove nearly all the ambient ozone, and cause a corresponding increase in NO_2 concentrations. For higher ambient NO concentrations, the removal of ozone by added NO is still very pronounced, but not so large as when initial NO concentrations are low. For nearly all the conditions, the reduction in ozone concentration is approximately equal, numerically, to the amount of added NO_x when the added NO_x amounts to less than about 50 ppb.

The fact that atmospheric ozone depletion (and NO_2 augmentation) are approximately equal to the added NO_x concentrations, when the added NO_x is less than about 50 ppb, allows Figure 50 to be used to estimate the setback that will be required in order to keep changes in ozone caused by roadway emissions below an arbitrary level. Singh et al. (1977) have indicated that ozone concentrations in remote locations are generally in the range from about 20 to 60 ppb. Using this as a guide, the effect of a street should probably be kept below about 40 to 50 ppb. The figure shows that under the worst conditions, the effects of a single street can be kept below about 40 to 50 ppb if we are about 20 meters removed from small streets with an ADT of about 1000 and about 250 m from a larger street with ADT of 10,000. However, the large freeways with ADT of about 50,000 should be 4 km away if their effects on ozone concentration are to be less than about 40-50 ppb. A requirement for such a large separation between a monitor and a major roadway is impractical, but may not really be necessary, because the ozone concentrations of greatest interest (peak-hour concentrations) are most likely to occur in the early-to-mid-afternoon. During those hours the traffic on the roadway is less than the 10% of ADT that was assumed in the preparation of Figure 50. Therefore, the influences of the roadway would be correspondingly less and the required separations could be reduced to a kilometer or two. The general areas in which the ozone monitors are to be located will usually be outside the major urban region, where streets are likely to have lower traffic volumes and be more widely spaced. Therefore, the requirements for rather large separations between an ozone monitor and nearby streets and highways will not be as stringent as they would be for locating a monitor within a heavily populated region. Furthermore, the analyses of ozone concentrations in the heavily populated areas suggest that the heavy NO emissions throughout those areas will already have reduced ozone concentrations to very low levels and thus have placed a limit on the possible effects of any nearby NO sources.

6.4.3. The Importance of Topographical Features

It was recommended that an ozone monitor not be placed in a valley but that a location on a knoll was preferable. This recommendation arises because of the destruction of ozone that takes place at the surface. In a valley cold air drainage and stable conditions, especially at

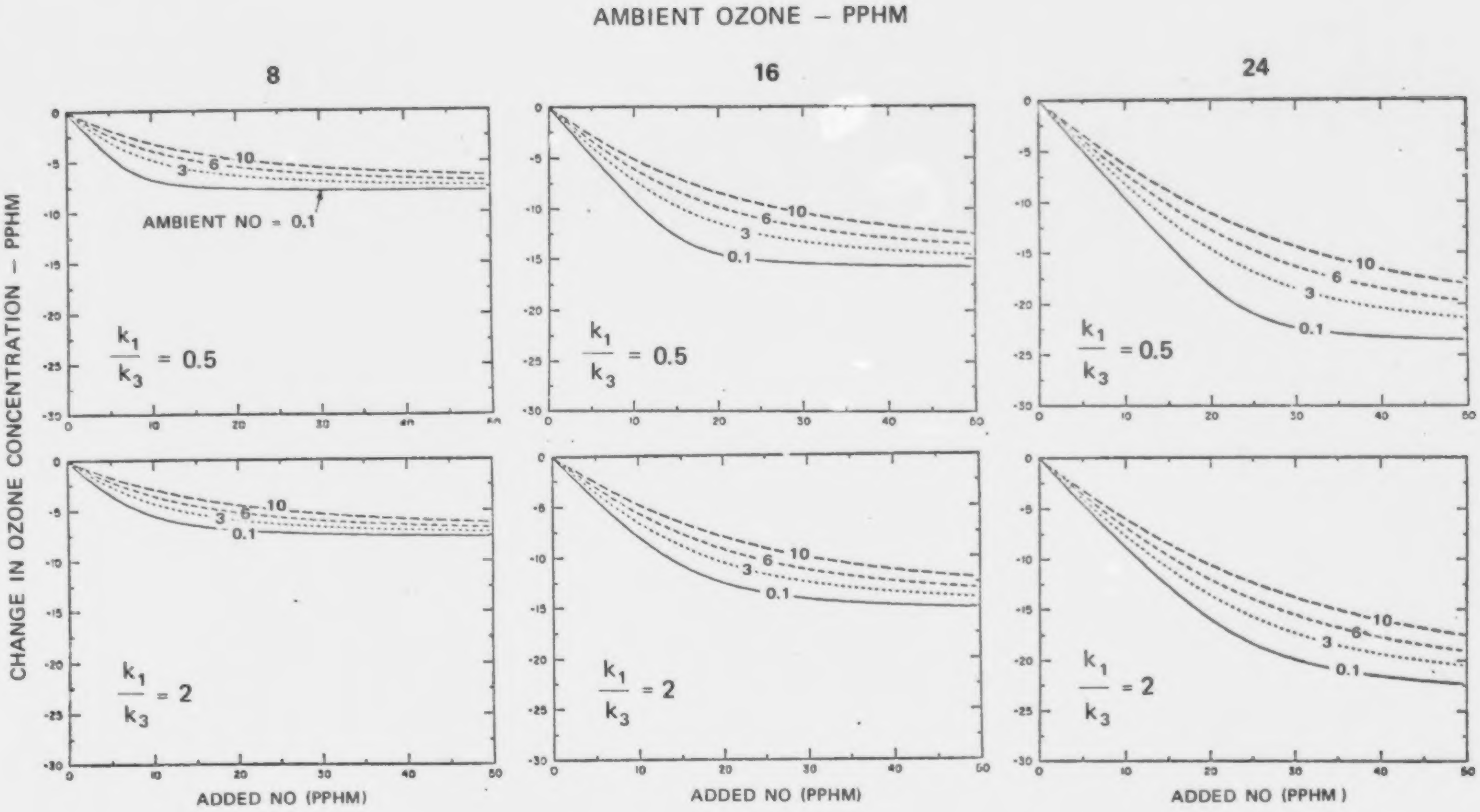


FIGURE 52 CHANGE IN OZONE CONCENTRATION FOR DIFFERENT AMOUNTS OF ADDED NO

night, will cause air to remain relatively stagnant and without vertical mixing. Under such conditions the destructive processes at the surface will quickly deplete any ozone that is present and the monitor will measure values that are less than is typical of the lower troposphere. Singh et al. (1977) have analyzed data from remote locations and found that the destructive processes at the surface are appreciable even when there are no NO sources nearby. Figure 53, from their report, shows an example of this effect. That figure shows the average ozone concentration for different hours of the day at two locations in Colorado. These stations are separated by less than 5 kilometers but station C-20 is in a valley about 200 meters below station C-23. During the daytime, when vertical mixing is generally good, the two stations show essentially the same average ozone concentrations However, at night when vertical mixing is generally poor, the destructive processes in the valley reduce concentrations by about 10 to 15 ppb below those at the mountain station.

6.4.4. Height of Inlet

It is recommended that inlets for ozone, NO_2, and NMHC monitoring be placed within a limited range of height, 3 to 15 m. The height range should be limited in order to allow comparisons of data collected at different stations to be made in such a way that data differences represent differences in the general pollutant concentration, rather than the effects of local sources and vertical gradients. To a large extent, practical considerations dictate that a fairly wide range of inlet heights be allowed in order to accomodate the special situations that will inevitably be encountered. The monitoring of the photochemical pollutants will not generally be concerned with local effects. All the siting criteria have been designed to provide measures of rather large, well mixed air volumes. The long periods of time required for the formation of ozone ensures that it will be reasonably homogeneous, so long as the setback recommendations are observed and local sinks are avoided. The hydrocarbon and NO_x measurements are also supposed to represent reasonably well mixed air masses so that vertical gradients should be small as long as local sources are avoided. Nevertheless, the two ends of the range, 3 meters and 15 meters, may serve somewhat different purposes. When the major objective of the monitoring is related to public health, then the 3 meter height is preferred over the 15 meter height because it is closer to the breathing level. Three meters is about as low as one can get and still avoid vandalism of the inlet. Lower heights are also likely to present obstacles to pedestrians. The upper end of the recommended height range, 15 meters, will provide samples that are more nearly representative of the well mixed air volume. An inlet of 15 meters should be reasonably well removed from the destructive processes at the surface. A higher inlet is also less apt to be influenced by local traffic sources.

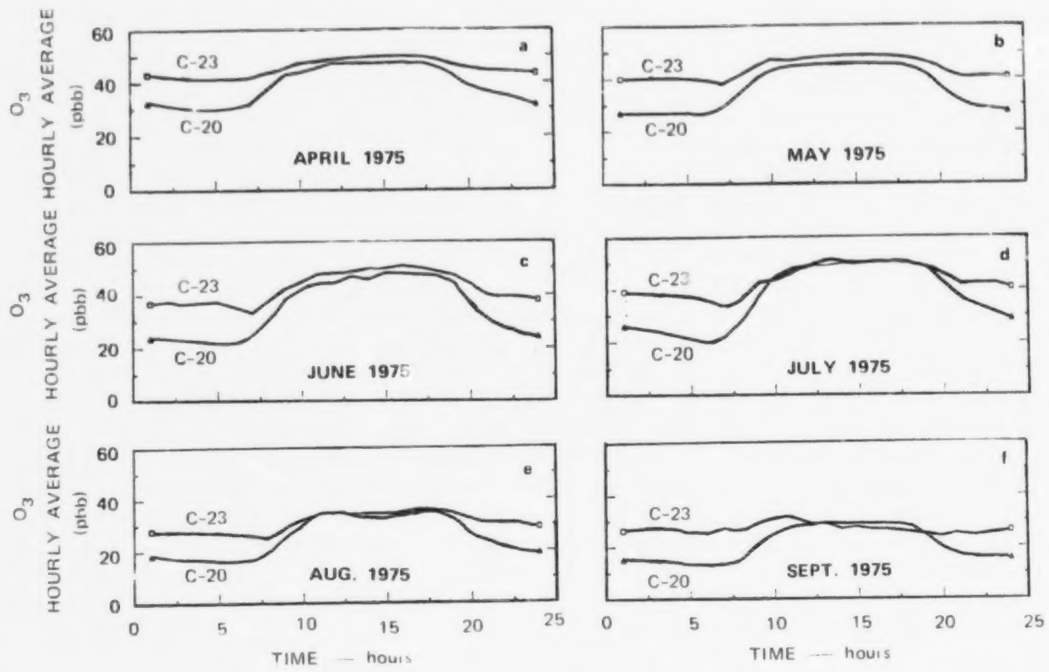


FIGURE 53 AVERAGE DIURNAL VARIATIONS IN OZONE CONCENTRATION AT TWO STATIONS NEAR RIO BLANCO, COLORADO

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Appendix A

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A literature review during the early phases of this project provided a collection of papers and reports on topics related to the measurement and distribution of the concentrations of the photochemical pollutants. The bibliography compiled during that literature review has been arranged alphabetically and is given on the following pages.

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Appendix B

Program WINDROSE

Program WINDROSE calculates the frequency distribution of wind direction and speed from standard National Climatic Center surface observation data. The program includes only those winds which accompany temperatures above 80°F (26.7°C) and occur during the daylight hours (0600 to 2000 LST).

WINDROSE was written for a CDC computer, but with a few modifications it can be compatible for use with other machines. The program will read WBAN/WMO hourly surface observations from tapes prepared by the National Climatic Center,. In addition to the data tape, the only other user supplied input is a card indicating the year/month/day start and stop dates of the data to be processed. The card format is 2F7.0.

```
      PROGRAM WNDROSE (INPUT.OUTPUT.TAPE1.TAPE2)
C
C     WIND ROSE PROGRAM - - - CALCULATES FREQUENCY DISTRIBUTION OF WIND
C       SPEED VS WIND DIRECTION.  PROGRAM WILL READ WBAN/WMO HOURLY
C      SURFACE OBSERVATION CARD IMAGE TAPES PREPARED BY THE NATIONAL
C      CLIMATIC CENTER, NOAA.  USER MUST ENTER START AND STOP DATES OF
C      DATA THAT IS  TO BE PROCESSED.
C
      DIMENSION DAT(80).CAT(17,7).CLASS(6).ICLAS(12),WNDIR(17)
      DIMENSION WSWD(16,6),NOC(16)
      DIMENSION TOTSPD(7),TOTDIR(17)
      DATA (WNDIR=4HCALM,3HNNE,3H NE,3HENE,3H E ,3HESE,3H SE,3HSSE,3H S
     2,3HSSW,3H SW,3HWSW,3H W ,3HWNW,3H NW,3HNNW,3H N )
      DATA (ICLAS=1,2,2,3,3,4,4,5,5,6,6,7)
      DATA (CLASS=          7H1.0-2.0,7H3.0-4.0,7H5.0-6.0,7H7.0-8.0,
     18H9.0-10.0,8H.GT.11.0)
 1    FORMAT (1H1,25X*WIND ROSES FOR ST. LOUIS FOR DURING *F8.0* TO*F8.0
     1/)
 2    FORMAT (/1H ,*ECF. NO. =*I4)
 3    FORMAT (/1H ,*P.E. NO. =*I4)
 4    FORMAT (/1H ,*REC. NO. =*I4)
 5    FORMAT  (2F7.0)
  6    FORMAT (5X,F6.0,F2.0)
 7    FORMAT (8X,F2.0,F2.0,4X,A1,F2.0)
 8    FORMAT (// ,30X*FREQUENCIES OF OCCURRENCES*//1H ,*DIRECT/CATEGORY
     1*6A10,3X*TOTAL*/)
 9    FORMAT (1H ,2XA4,9X,7(F8.1,2X))
 10   FORMAT (8A10)
 11   FORMAT (1H ,8A10)
 12   FORMAT (// ,30X*PERCENTAGE  OF OCCURRENCES*//1H ,*DIRECT/CATEGORY
     1*6A10,3X,*TOTAL*/)
 13   FORMAT (/1H ,I5,2F10.0,3F10.1,3I10,F10.0)
 14   FORMAT (/1H ,*CALMA =*F10.2,5X*NO. OF OBS. =*I10/)
 15   FORMAT (1H ,16I5)
 16   FORMAT (/1H ,*NO. OF CALM OBSERVATIONS:*F7.1/)
18    FORMAT(/1X,*COLUMN TOTAL*3X,7(F8.1,2X))
      CALL MEMSETX (0.0.CAT.119) $ NOBS=0
C
C  READ START AND STOP DATES TO BE PROCESSED - FORMAT IS 2F7.0
C
      READ 5.BDATE.EDATE
      PRINT 1.BDATE.EDATE
C
C  READ SURFACE OBS TAPE - WRITTEN FOR CDC COMPUTER
C
 100  BUFFER IN (1.0) (DAT(1).DAT(80))
      IF (UNIT(1)) 130.110.120
110   NF=NF+1
      PRINT 2.NF
      GO TO 200
120   NP=NP+1
      PRINT 3.NP
130   NR=NR+1
      LEN=LENGTH(1)
       DO 180 I=1.LEN.8
```

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```
       DECODE (13,6,DAT(I)) DATE,HOUR
      IF (DATE.LT.BDATE) GO TO 180
      IF (DATE.GT.EDATE) GC TO 200
C
C   CHECK FOR TIME CF DAY
C
      IF (HOUR.LT.6.0.CR.HOUR.GT.20.0) GO TO 180
      DECODE (19,7,DAT(I+3)) DIR,SPD,ITX,TT
      IF (ITX.EQ.1HX) GO TO 140
      IF (ITX.EQ.1HO) GO TO 150
      TT=100.+TT
      GO TO 150
 140  TT=-TT
150   CONTINUE
C
C   CHECK FCR TEMPERATURE LESS THAN 80 DEG F
C
      IF(TT.LT.80.) GO TC 180
C
C           CONVERT WIND SPEED UNITS (KTS TO MPS)
C
      WSPD=SPD*0.51479
      IF (WSPD.GE.11.0) GO TO 160
      IWS=WSPD+1.0 $ GO TC 170
 160  IWS=12
 170  IC=ICLAS(IWS)
C
C  CONVERT WBAN CODES INTC 16 WIND DIRECTICNS
C
C
      CALL WINDIR (DATE,DIR,WDIR,IWD)
      CAT(IWD,IC)=CAT(IWD,IC)+1.0 $ NOBS=NOBS+1
  180  CONTINUE
       GC TC 100
 200  PRINT 8,CLASS
      DO 201 I=2,17
       TOT=0.0
      DO 202 L=2,7
      TOT=CAT(I,L)+TCT
202   CONTINUE
      TOTDIR(I)=TOT
201     CONTINUE
      ATOT=0.
      DO 203 L=2,7
      TOT=0.0
      DO 204 I=2,17
      TOT=TOT+CAT(I,L)
204    CONTINUE
      TOTSPD(L)=TOT
      ATOT=ATOT+TOT
203   CONTINUE
      DO 210 I=2,17
      PRINT 9,WNDIR(I),(CAT(I,L),L=2,7),TOTDIR(I)
 210  CONTINUE
      PRINT 18,(TOTSPD(L),L=2,7),ATOT
      PRINT 16,CAT(1,1)
C
C          COMPUTE THE PERCENTAGE OF OCCURRENCES AT EACH DIRECTION IN EACH
C     WIND SPEED CLASS.
      DO 220 IW=2,17
      DO 220 IC=2,7
      WSWD(IW-1,IC-1)=CAT(IW,IC)*100.0/NOBS
      IF (CAT(IW,IC).GT.0.0) NOC(IW-1)=IC-1
  220 CONTINUE
      CALMA=CAT(1,1)*100.0/NOBS
      PRINT12,CLASS
      DO 205 I=2,17
 205  TOTDIR(I)=TOTDIR(I)/NOBS*100.
      DO 206 I=2,7
 206  TOTSPD(I)=TOTSPD(I)/NOBS*100.
      ATOT=ATC  NOBS*100.
      DO 230 I=1,16
      PRINT 9,WNDIR(I+1),(WSWD(I,L),L=1,6),TOTDIR(I+1)
  230 CONTINUE
      PRINT 18,(TOTSPD(L),L=2,7),ATOT
      PRINT 14,CALMA,NOBS
      STOP200
       END
```